Fall 11-11-2015

Exploration of the materials paradigm with respect to bioinspiration

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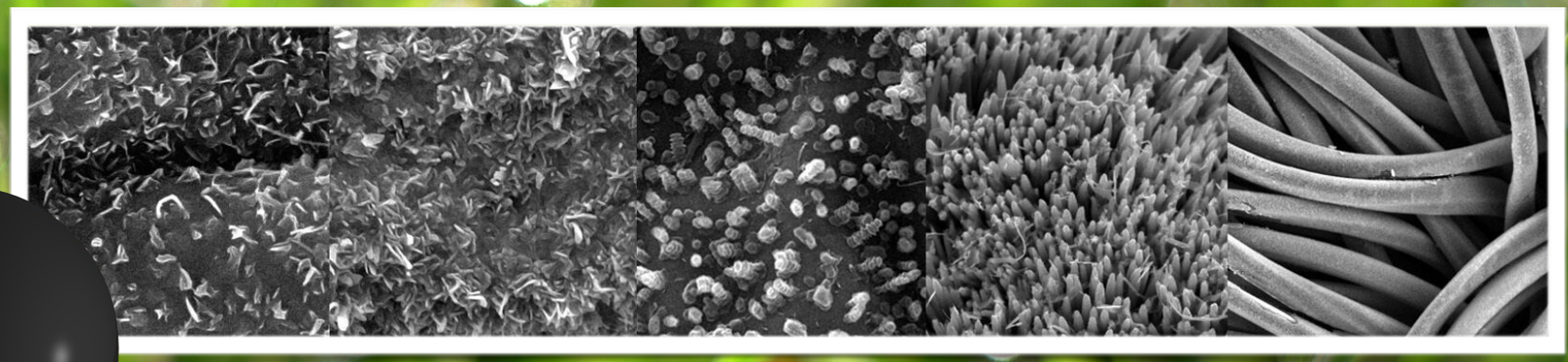
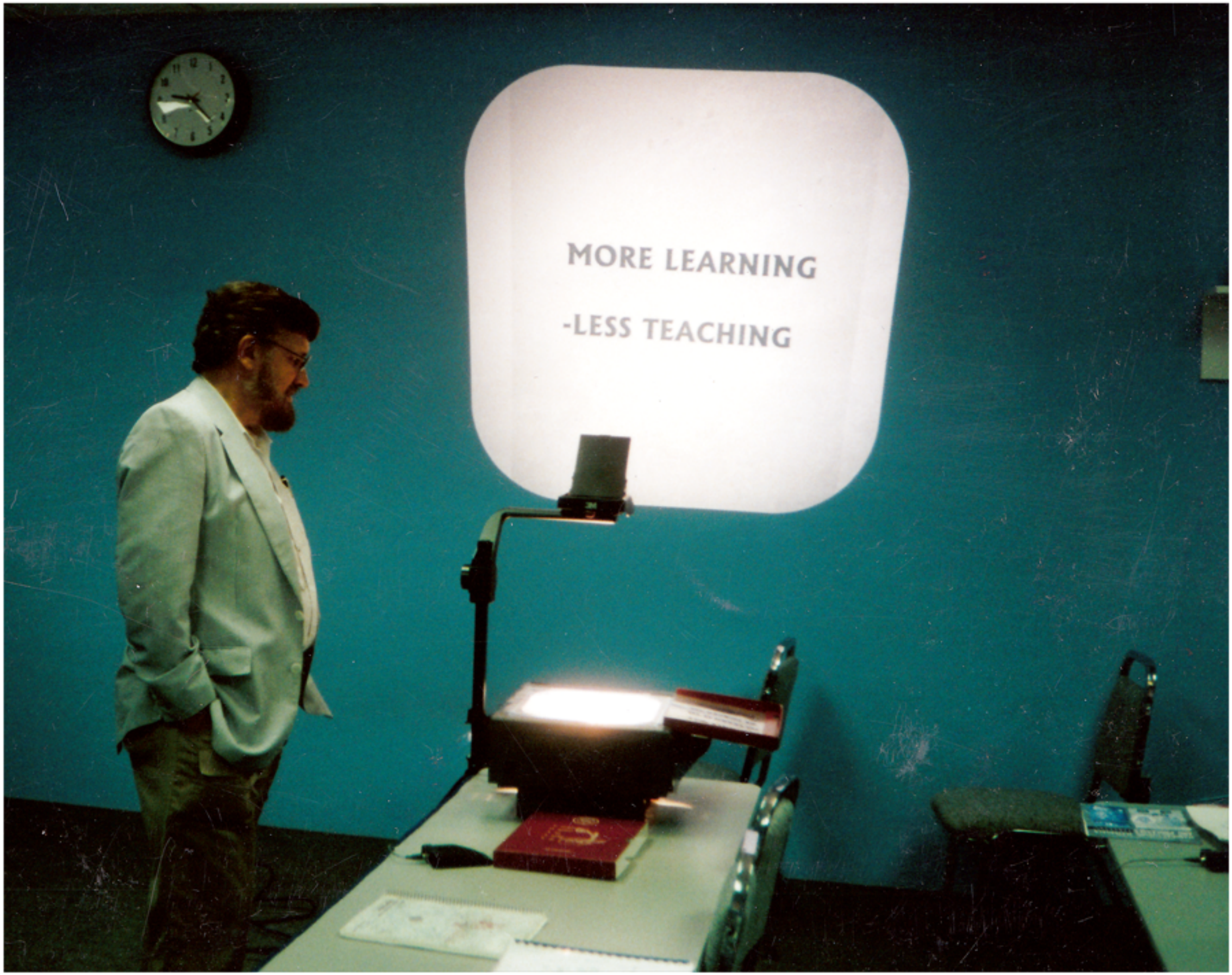


The Materials Paradigm & Bioinspiration

John A. Nychka

Chemical & Materials Engineering, University of Alberta

November 11, 2015


MORE LEARNING
-LESS TEACHING

Acknowledgements

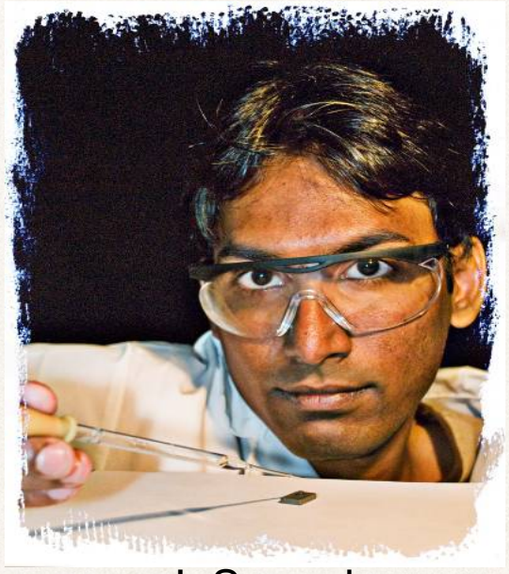
- Financial Support: NSERC and the University of Alberta
- Steven Williams (Greehouse Supervisor)
- Arlene Oatway (SEM)
- Collaborators: Prof. N.V. Semagina, Prof. H.J. Chung (U of A)
- Past Industrial Partner: Syncrude Canada, Ltd.
- HQP:

K. Jensen

J. Deutsch

N. Lun

Y. Chen



J. Samad

mati
materials at the interface

UNIVERSITY OF ALBERTA
QUAECUMQUE VERA

ENGINEERING
UofA

NSERC
CRSNG

Golden Nuggets

- Our thoughts are clouded by biases.
- Paradigms evolve; adapt or be left behind.
- Life obeys: "good enough, with what it has, for right now".
- Looking is not seeing.
- Seeing is not imagining.

Bioinspiration

Ask nature

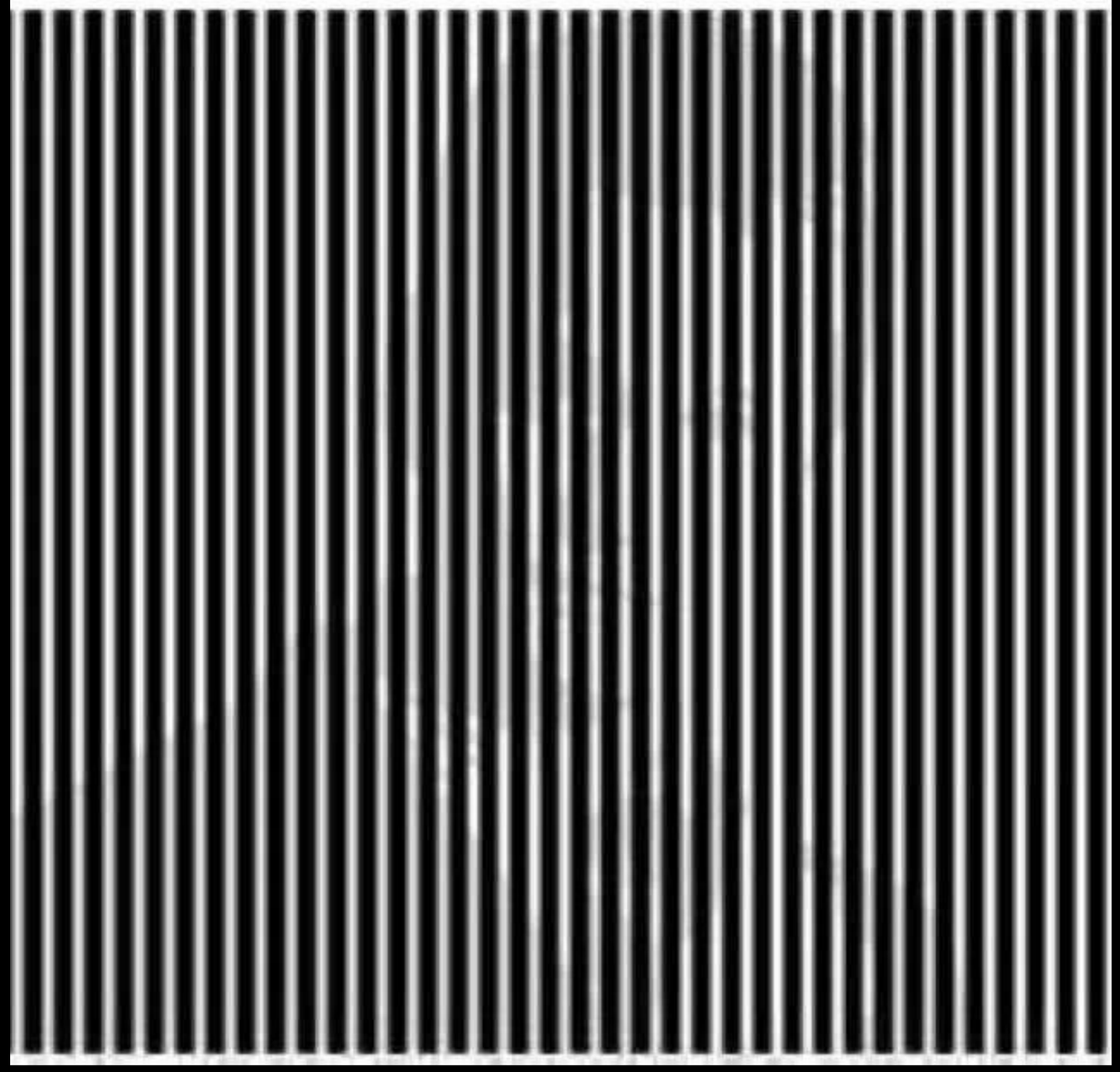
Mother Nature

Biomimicry

Bioinspired

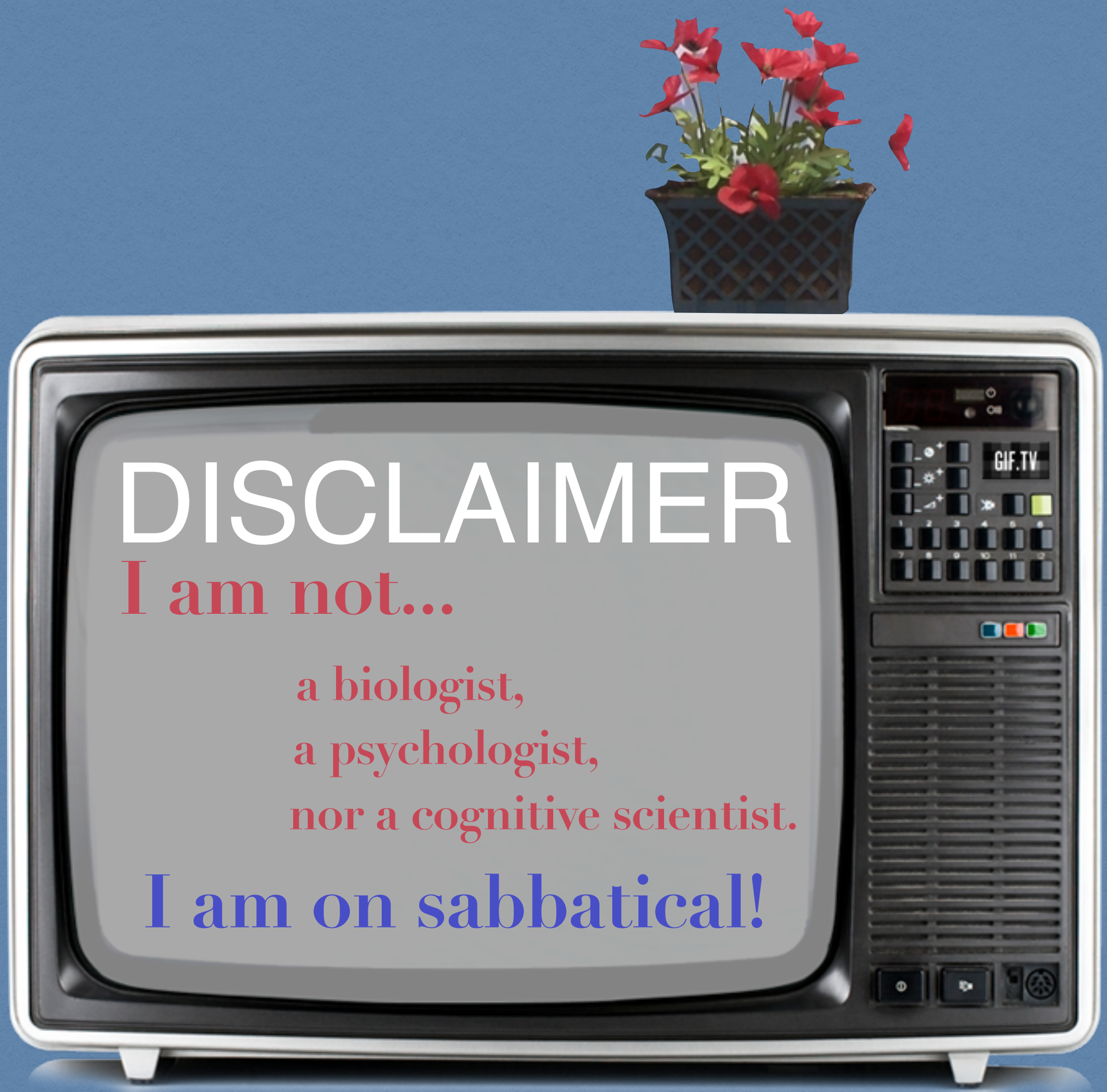
Nature got there first

Shake your head



"It is impossible to begin to learn that which one thinks one already knows."

- Epictus (c. 55-c. 135)


DISCLAIMER
I am not...
a biologist,
a psychologist,
nor a cognitive scientist.
I am on sabbatical!
GIF.TV

The Journey

- Learning, Reasoning & Intellectual Development
- Paradigms
- Life as a Satisficer
- Observation vs. Interpretation
- Discovery vs. Innovation

START

PARADIGMS

DISCOVERY

INTERPRETATION

SATISFICING

LEARNING

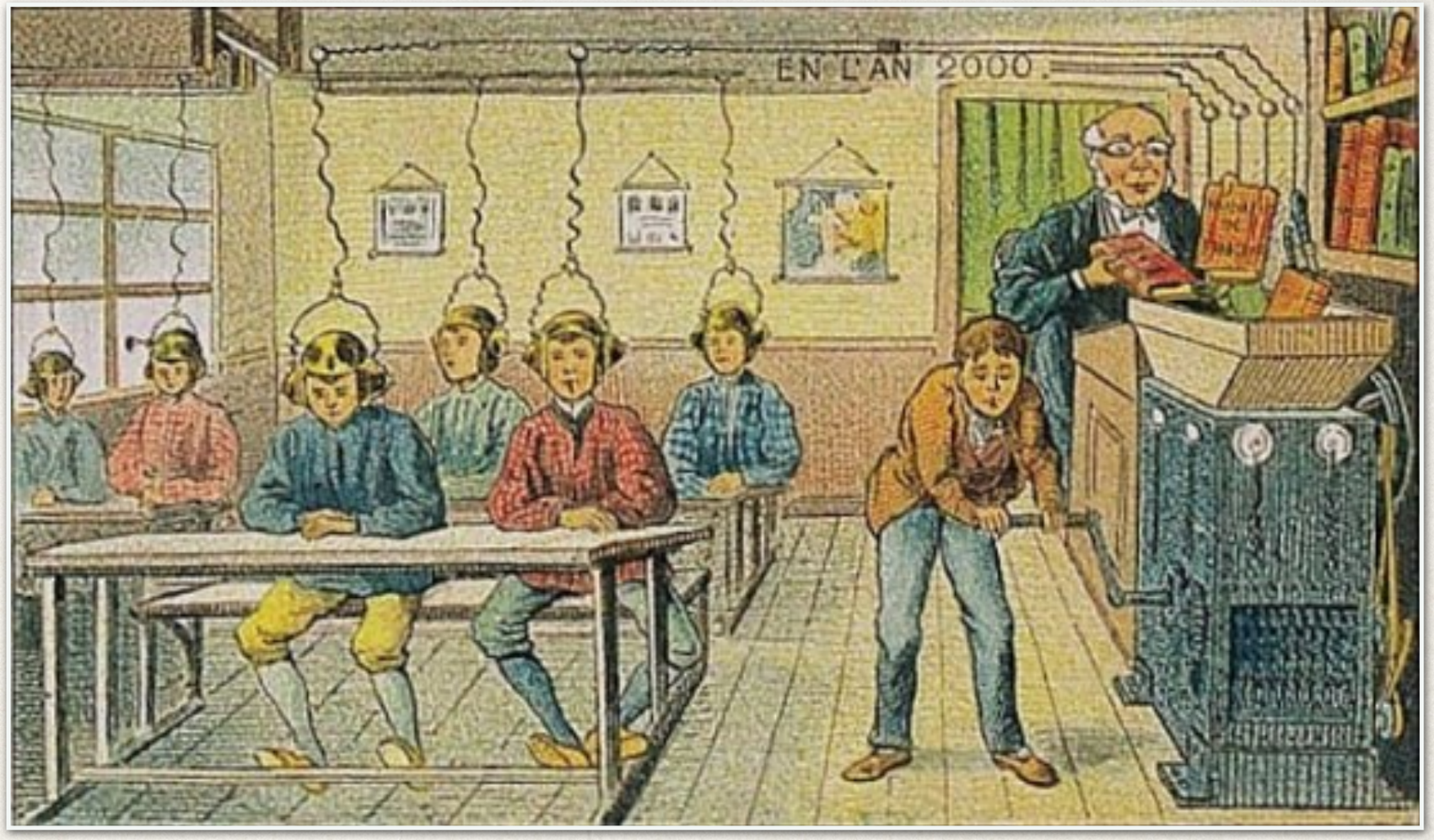
Learning

Acquisition

Reinforcing

Modification

Of knowledge... behaviours, skills, values, preferences...



The Domains of Learning

(Revised Bloom's Taxonomy)

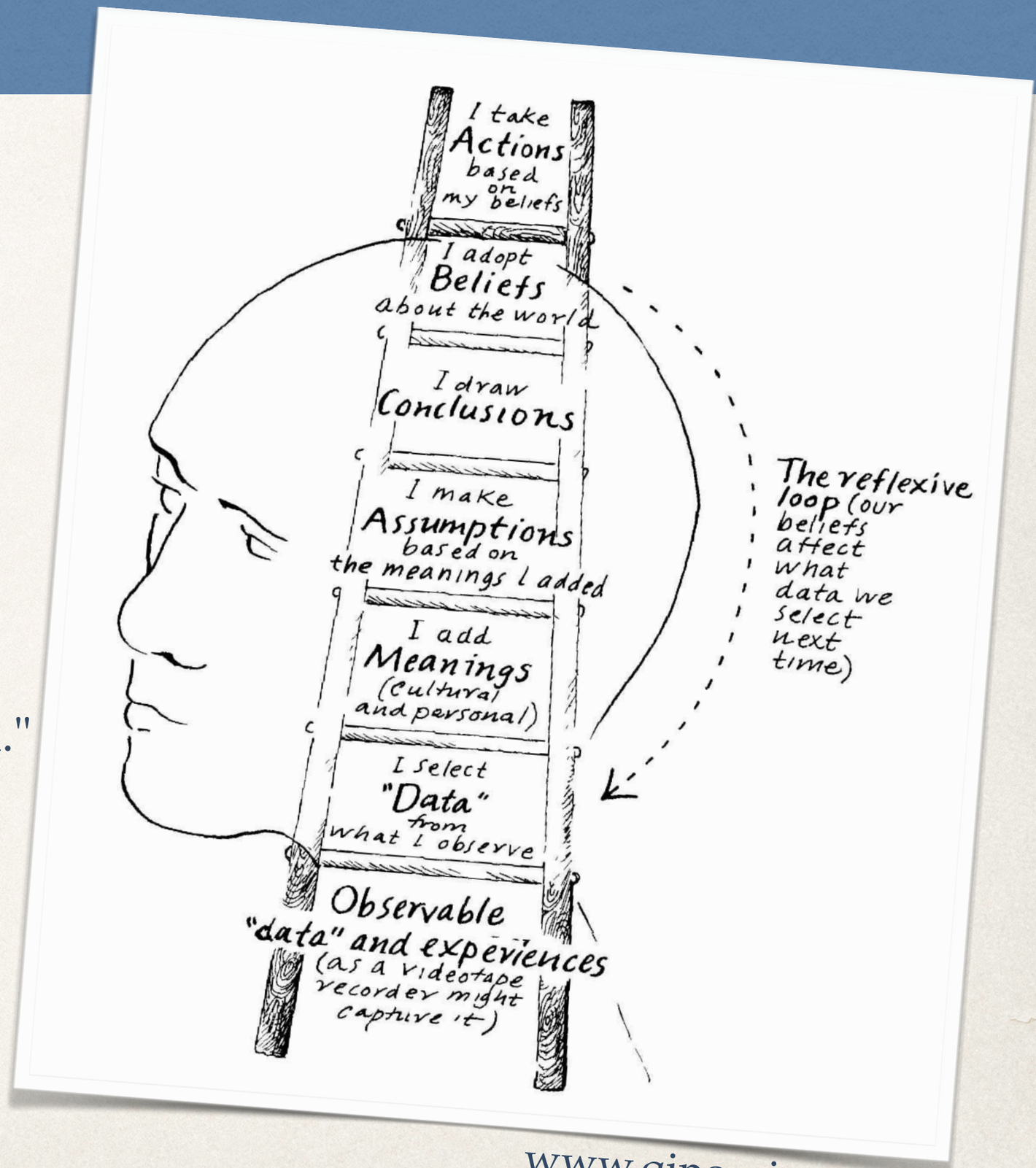

"WE ARE CONNECTED TO REALITY
BY OUR MODEL OF IT."
- ROGER MARTIN

Mental Models

Formed through reflection & inquiry

Quality is impeded by our feelings that:

- "Our beliefs are the truth.
- The truth is obvious.
- Our beliefs are based on real data.
- The data we select are the real data."



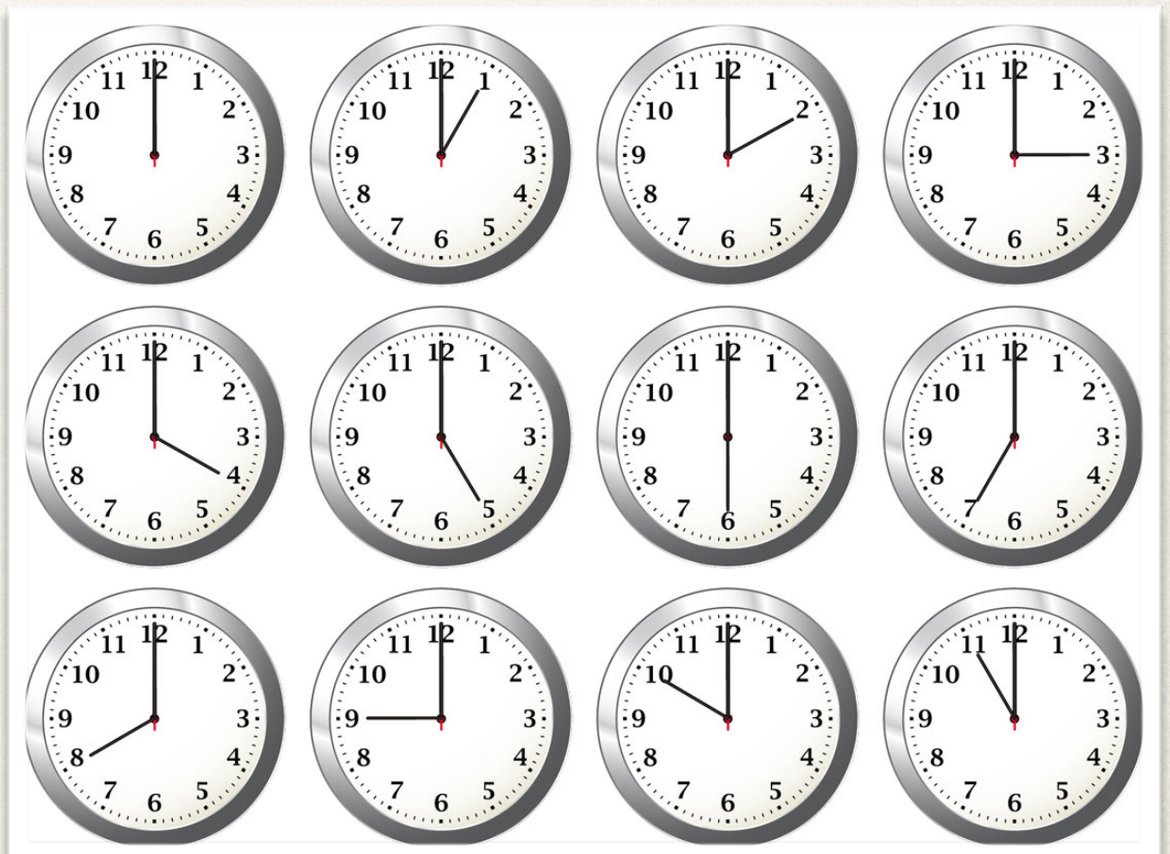
www.qinomics.com

Mental Models

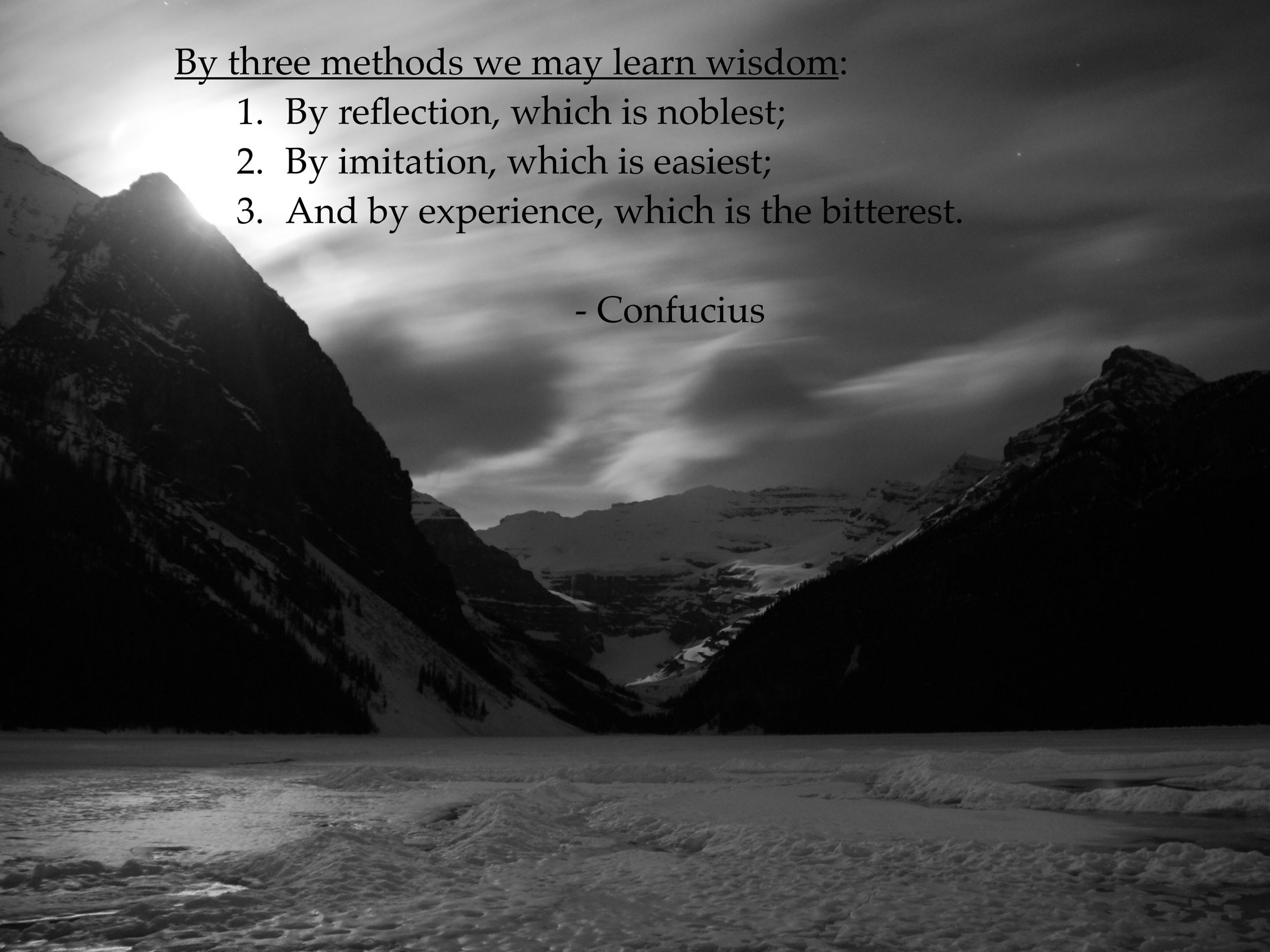
Contented Model Defense

www.usimetro.com

Optimistic Model Seeking



www.jackholesrealm.wordpress.com



By three methods we may learn wisdom:

1. By reflection, which is noblest;
2. By imitation, which is easiest;
3. And by experience, which is the bitterest.

- Confucius

Reasoning

WHAT + HOW -> RESULT

(thing) (working principle) (observed)

Deduction: informs justification

1. WHAT + HOW -> ???

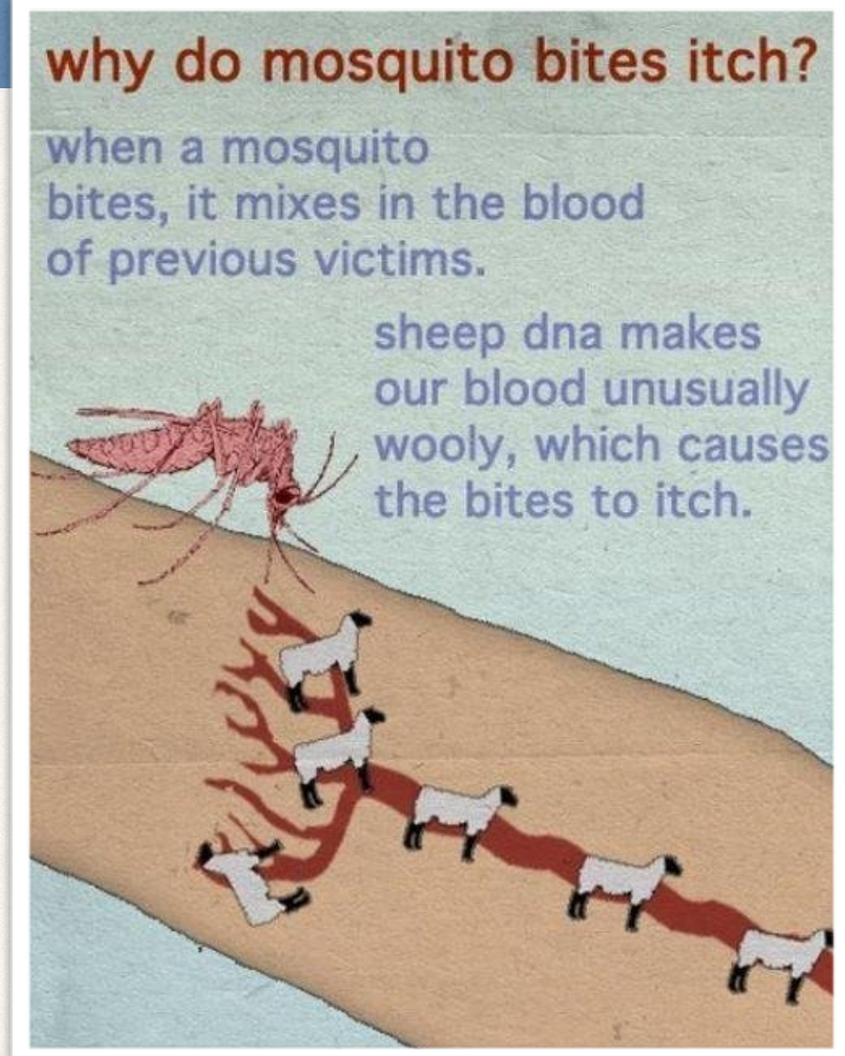
Induction: informs discovery

2. WHAT + ??? -> RESULT

Abduction: leads to attainment of aspired value

3-1. ??? + HOW -> VALUE Conventional closed problem solving

3-2. ??? + ??? -> VALUE Design and open-ended problem solving



K. Dorst, *Design Studies*, 32, (2011) 521-532

Intellectual Development

Perry's schema: Intellectual development

	Most entering students / Dualism	Most undergraduates / Multiplicity	Some Seniors / Relativism	Some graduates / Commitment
Knowledge	All knowledge is known; there are clear right and wrong answers	Most knowledge is known; there are right and wrong ways to find answers	Most knowledge is not known; everyone is entitled to their opinion	All knowledge is contextual; within a context, there are right and wrong answers
Instructor	A source of knowledge	A source for the right way to get knowledge	Instructors provide either (1) a resource for the thinking process or (2) is irrelevant	Sources of expertise
Student	Receiver and demonstrator of knowledge	Must learn how to learn and to work hard	Must learn to think for oneself, to support opinions	Study different contexts and perspectives;
Peers	Peers are not considered to be a source of knowledge	Beginning to be viewed as a possible legitimate source of knowledge	Can be considered legitimate sources when following reason and provide support	Knowledge is learned from others, along with experience and reflection

Adapted from: http://www.cse.buffalo.edu/~rapaport/perry.positions.html

Zone of Proximal Development

www.blogs.corpu.com

Issue: we cannot truly "ask" nature...

Cognitive Bias

We are prone to many forms of bias (short list):

- Confirmation bias - we seek out and pay particular attention to information that supports our existing beliefs

- Fundamental attribution error - we assign causation without actually investigating causes

- Embodied cognition - our thoughts are rooted in the physical, so our use of physical metaphor is used to comprehend abstract ideas and concepts

- Endowment effect - we place more value on things through ownership alone

- The IKEA Effect - we place more value on cheap furniture we have to build ourselves

Stance: a belief system and commitment

- **About the World**

- Existing models do not represent reality; they are constructions

- Opposing models are to be leveraged, not feared

- Existing models are imperfect; better models exist that are not yet seen

- **About Ourselves**

- I am capable of finding a better model

- I can wade into and get through the necessary complexity

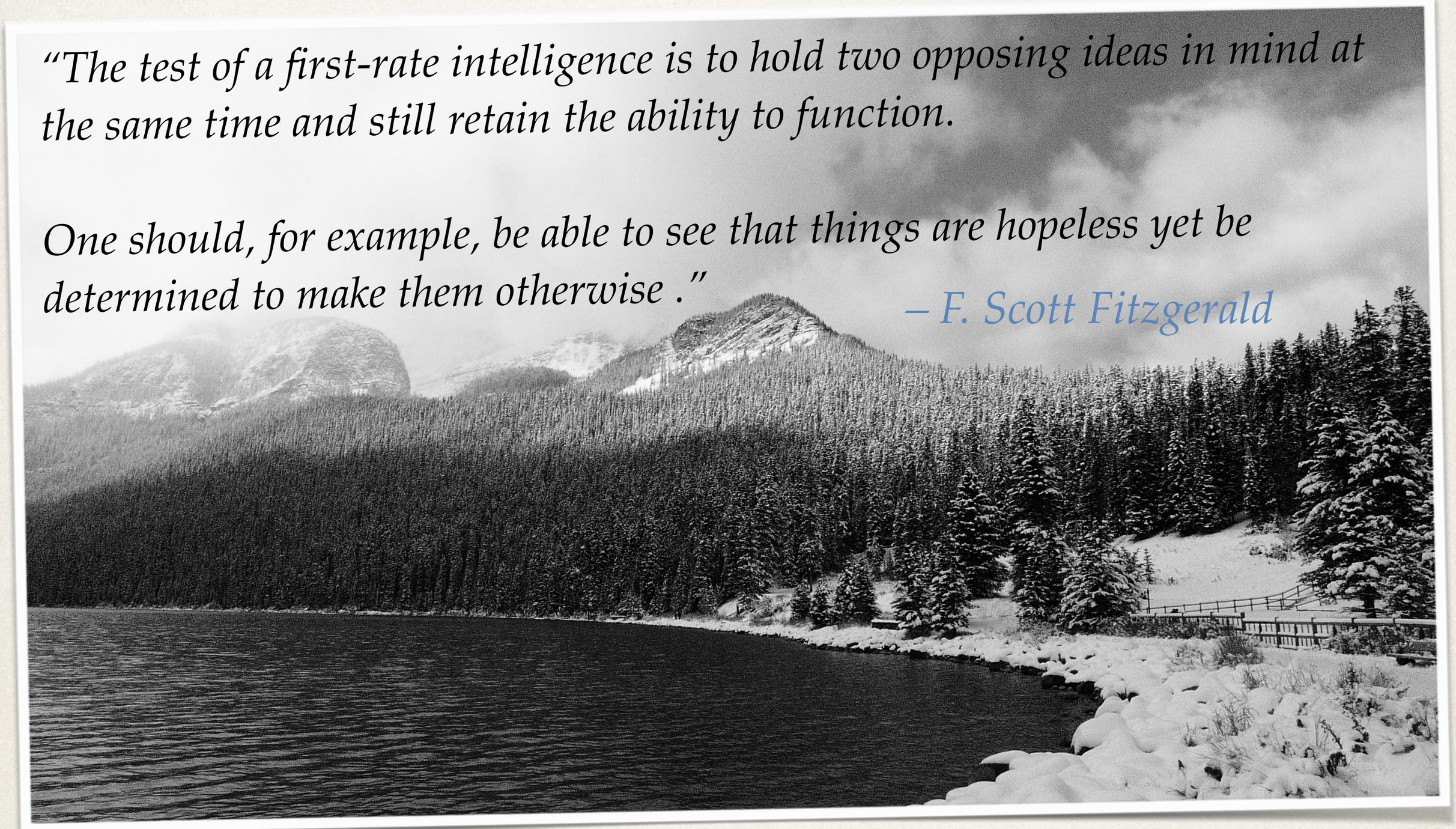
- I give myself the time to create a better model

R.L. Martin, *The Opposable Mind*, 2009

"The test of a first-rate intelligence is to hold two opposing ideas in mind at the same time and still retain the ability to function.

One should, for example, be able to see that things are hopeless yet be determined to make them otherwise ."

– F. Scott Fitzgerald



Opportunities

Learn about and be cognizant of:

- Our biases
- Others' perspectives
- Contrary beliefs, models, and paradigms
- What life is really doing...

Definitions...

John Houseman, "The Paper Chase" 20th Century Fox/Koball Collection

bi·ol·o·gy

/bīˈäləjē/

noun

The study of living organisms, divided into many specialized fields that cover their morphology, physiology, anatomy, behavior, function, origin, evolution, and distribution.

e.g., the plants and animals of a particular area.

physiology, behavior, and other qualities of a particular organism or class of organisms.

bio·in·spired

\ ˈbī-(ˌ)ō-ˌin-ˈspīrd, -ˈspī-ərd \

adjective

Inspired by or based on biological structures or processes.

e.g., "Making bioinspired materials has been a popular notion of research for some time, but achieving such complexity through synthetic techniques offers considerable challenges."

— David Filmore, Today's Chemist At Work, April 2003

par·a·digm

/ˈperəˌdīm/

noun

A world view underlying the theories and methodology of a particular scientific subject.

e.g., "the discovery of universal gravitation became the paradigm of successful science"

Characteristics of a Paradigm

1) It is "*sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific* activity"

2) It is "*simultaneously, [sufficiently] open-ended to leave all sorts of problems for the redefined group of practitioners to resolve.*"

T.S. Kuhn, *The Structure of Scientific Revolutions*,1996

Hierarchy

Performance

Properties

Evolution

Structure

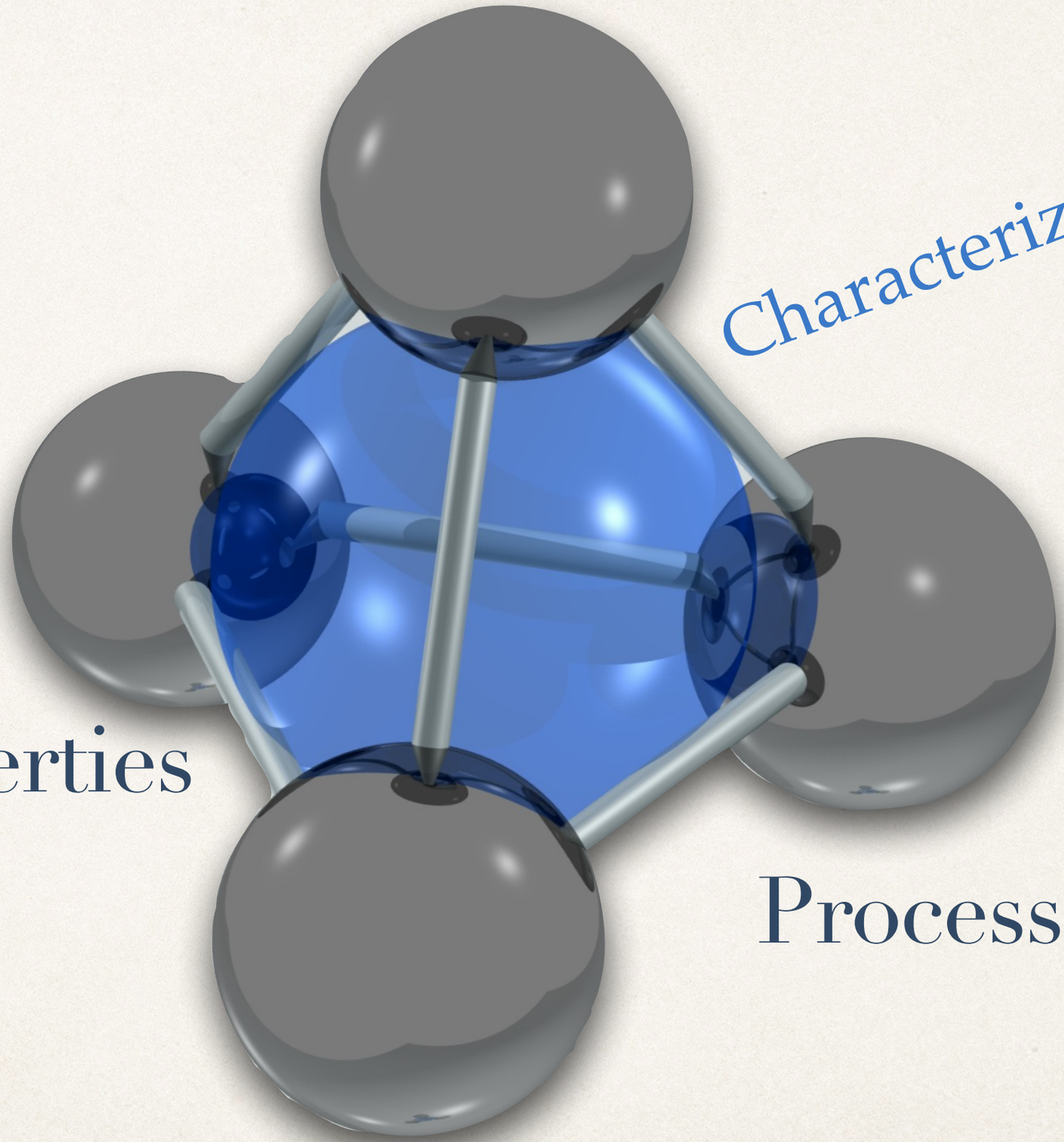
Synthesis

Function

Processing

Materials Paradigm

Performance



Characterization

Properties

Processing

Structure

The Paradigm of Materials Science

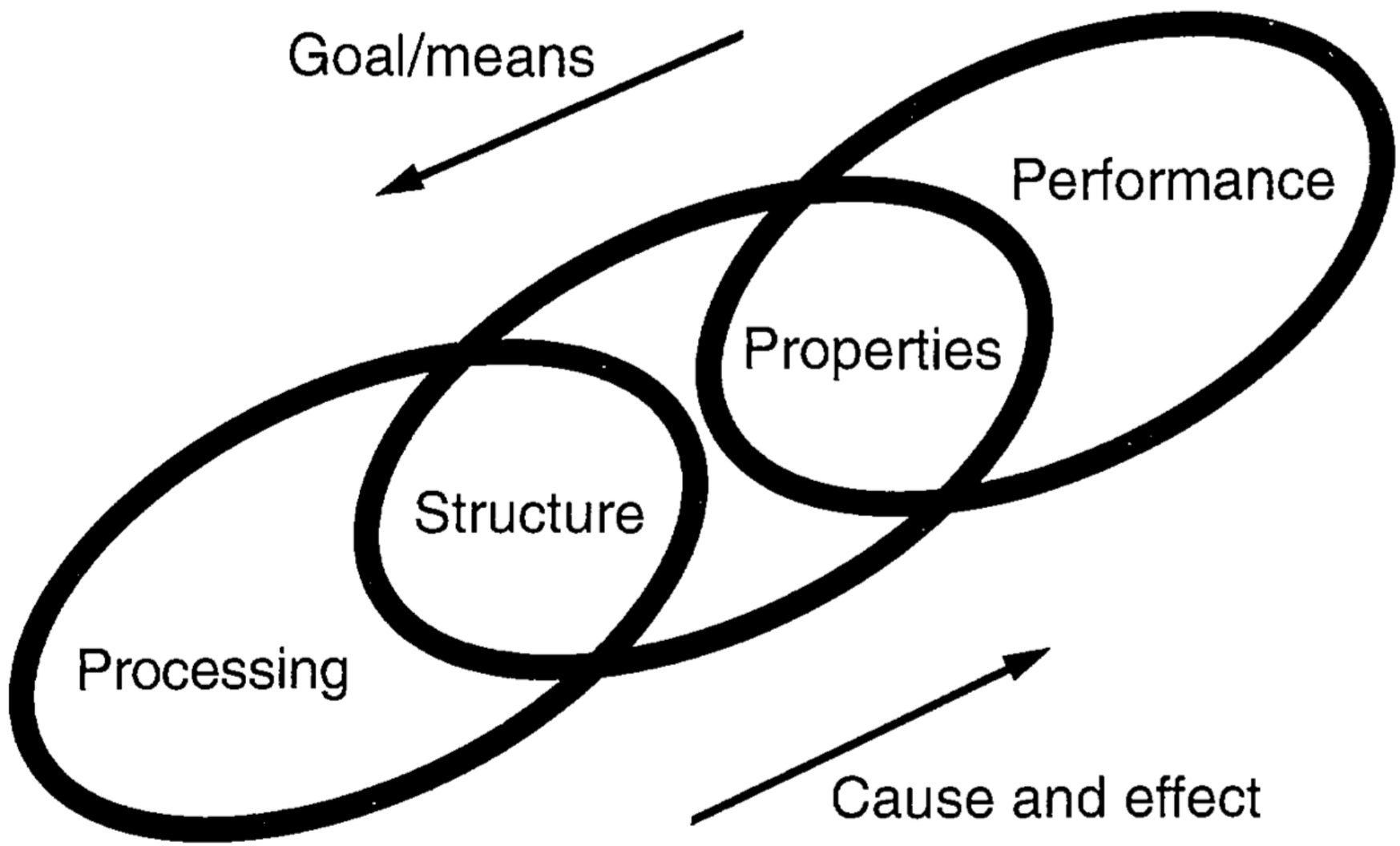
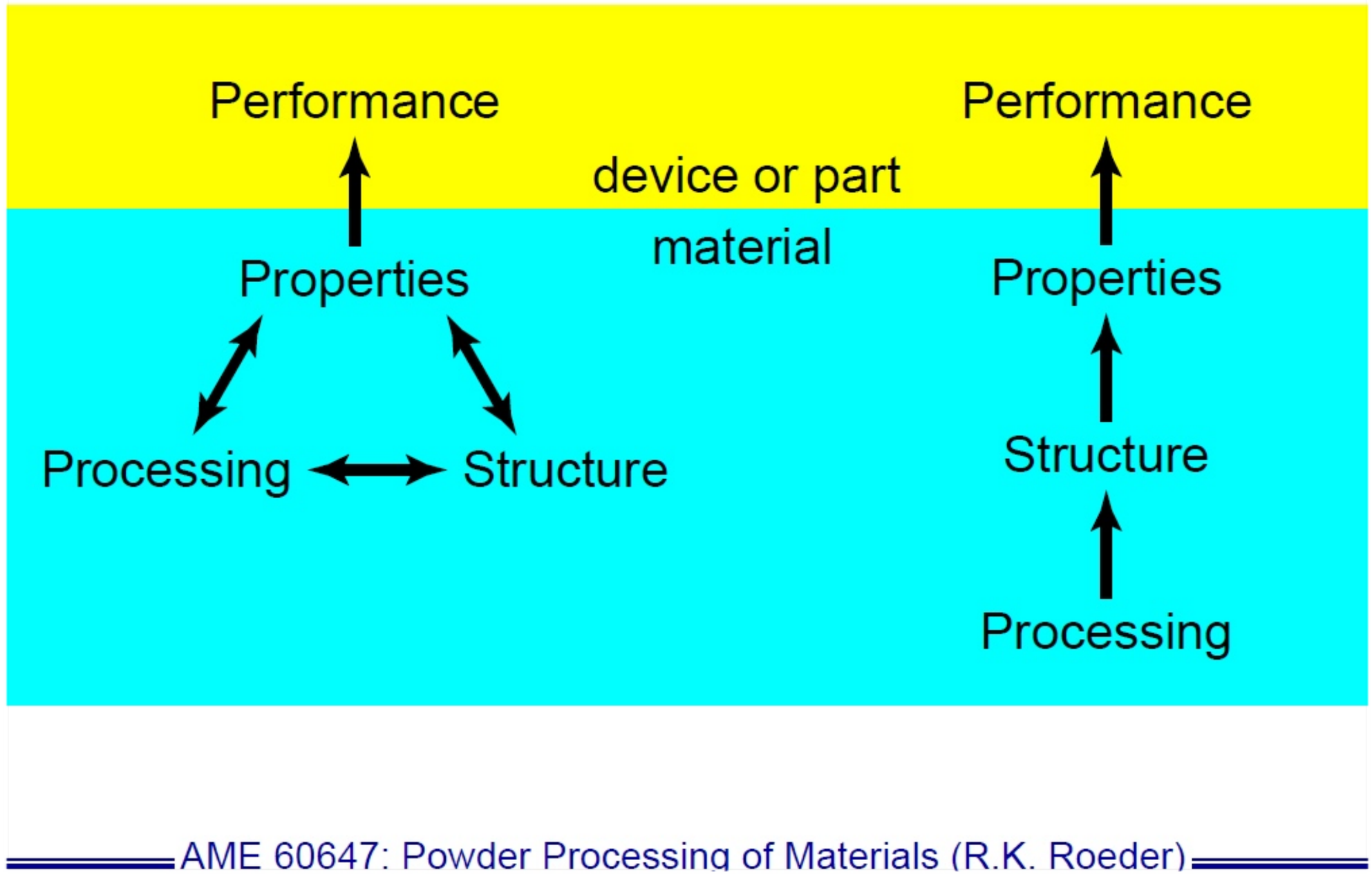


Fig. 1. Three-link chain model of the central paradigm of materials science and engineering.

G.B. Olson, Science 277, 1997

Materials Engineering Paradigm

Materials Engineering Paradigm



Materials as Systems

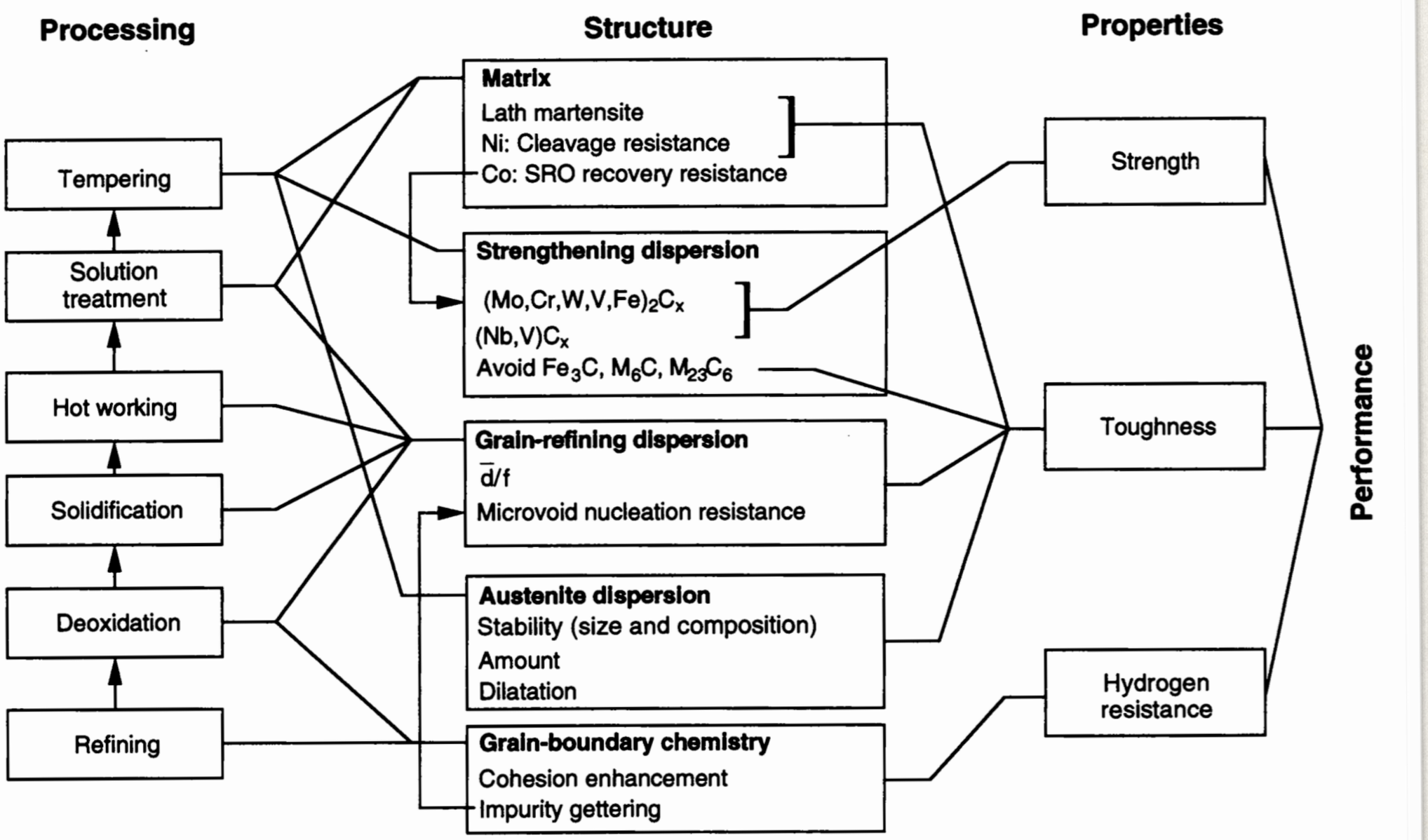
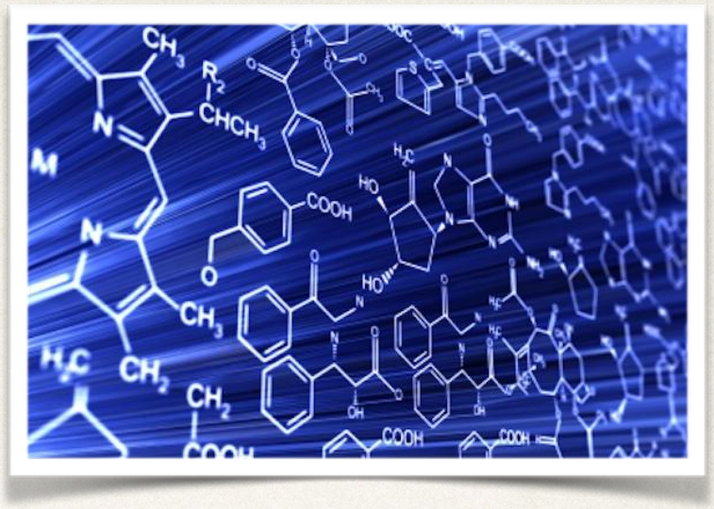


Fig. 2. Materials system chart for high-performance alloy steel (*1*).

G.B. Olson, Science 277, 1997

Biological Paradigms

Chemical Paradigm: the idea that life is an extremely complex form of chemistry.



Information Paradigm: the view that life is not just ‘chemistry’ but ‘chemistry-plus-information’.

Code Paradigm: the view that ‘information’ embodies meaning, implicit with a genetic code in every cell.

M. Barbieri, Biosemiotics, 6, 33-59 (2013)

Merged Paradigm

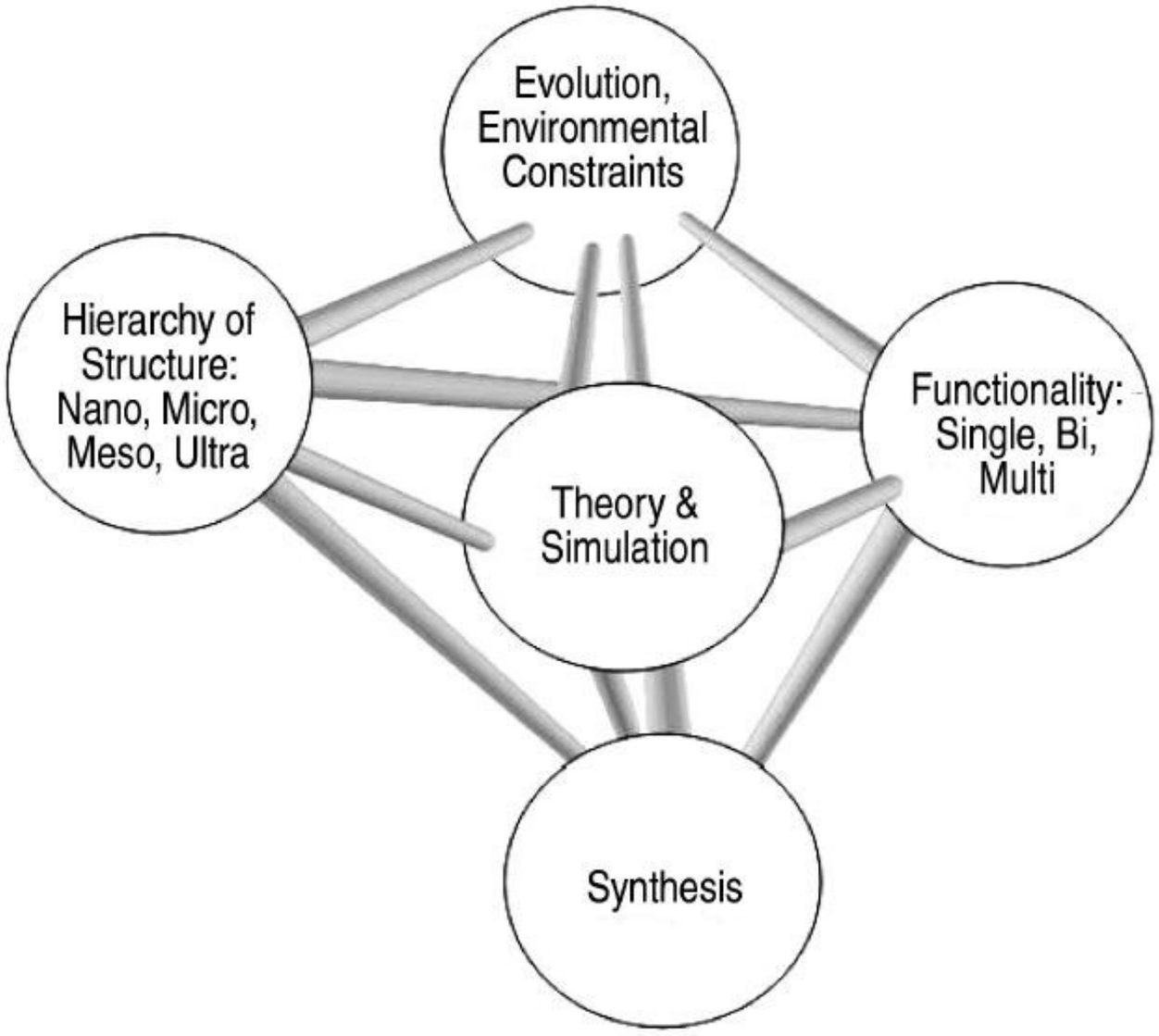


Figure 1. A schematic representation of constraints/components in the study of biological systems (image courtesy of E. Arzt).

A. Hodge and M. Meyers, JOM, 2006

Merged Paradigm

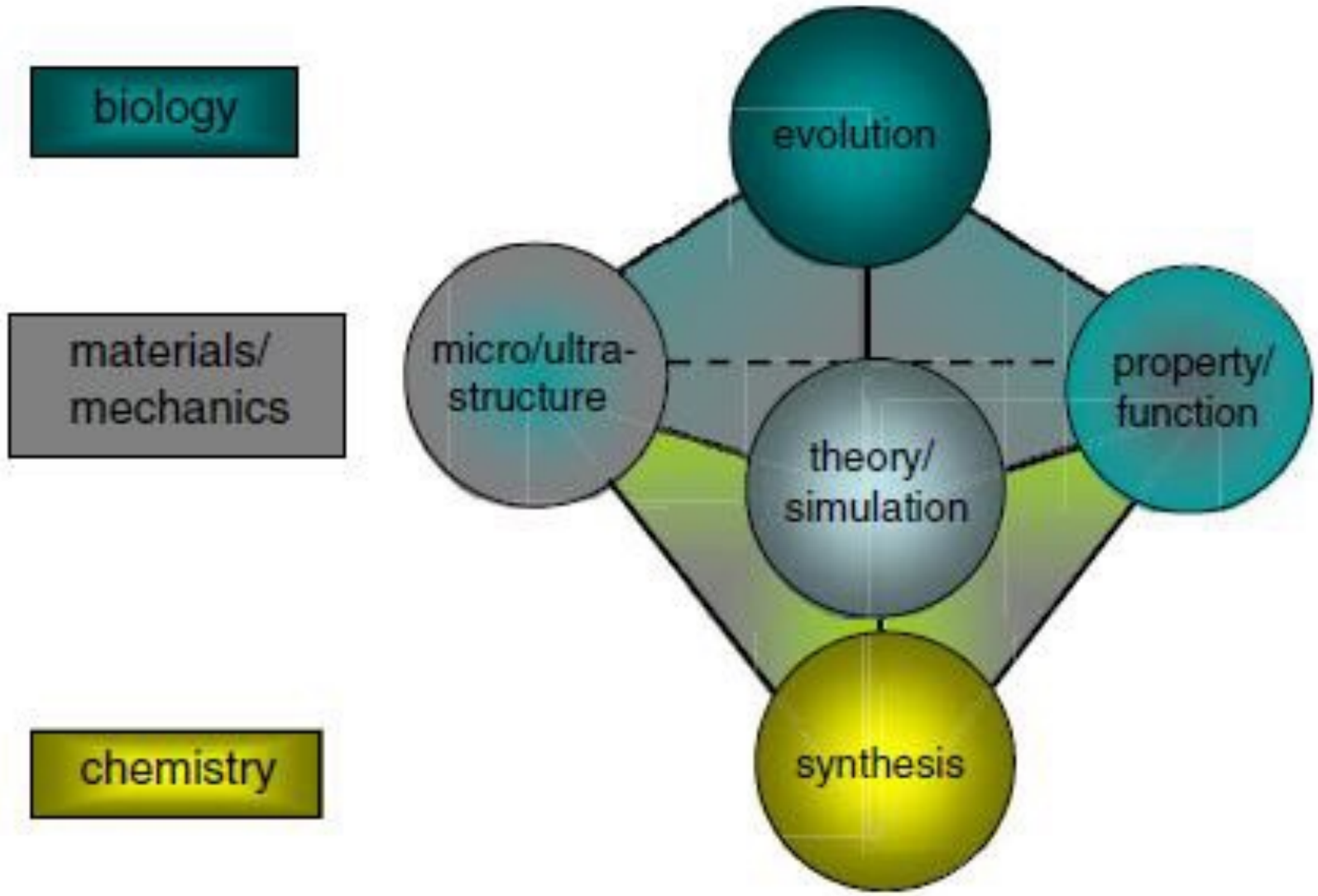
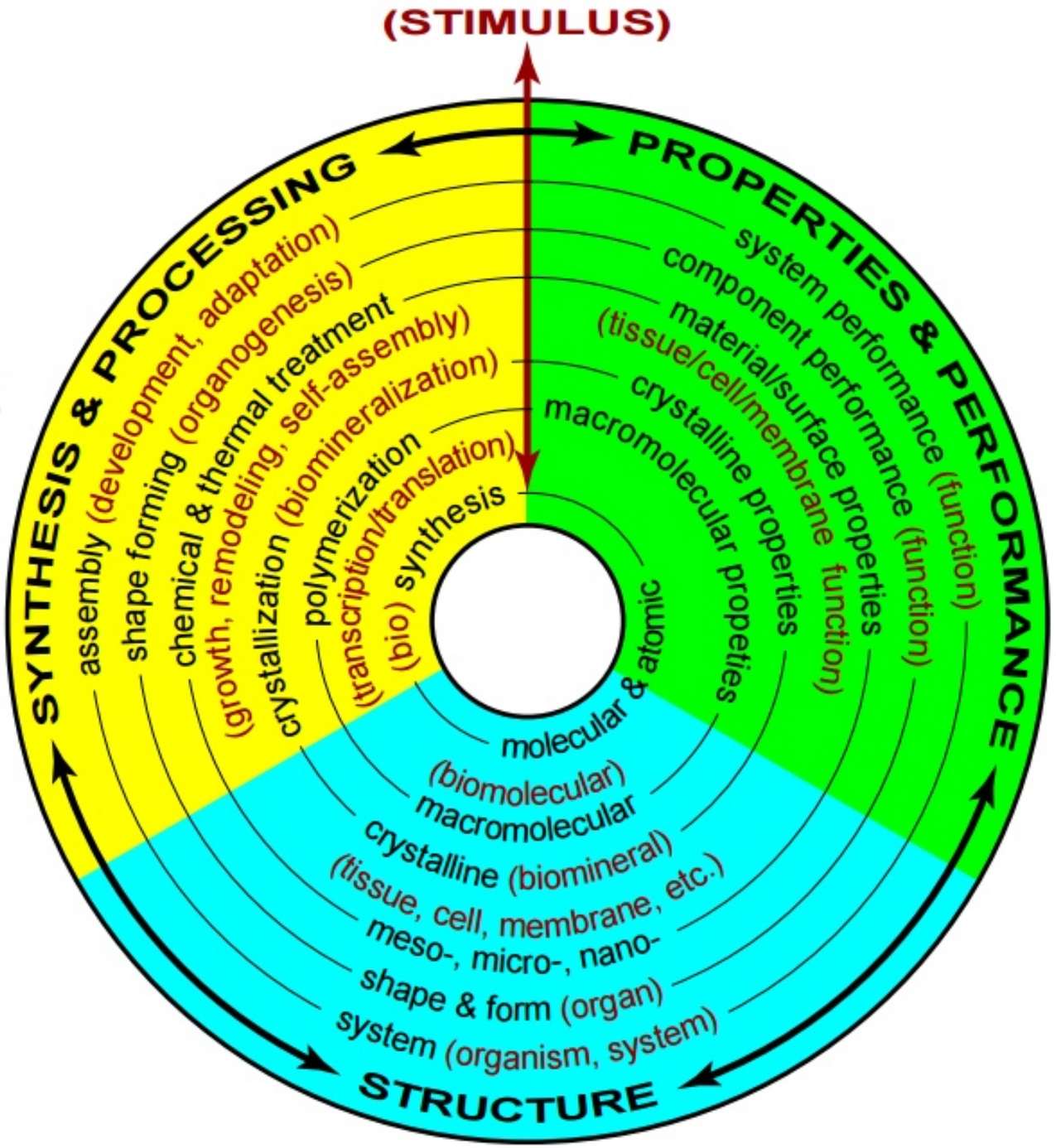


Fig. 1. The interplay between different disciplines in the investigation of attachment systems. A thorough understanding of evolutionary principles and of the functional properties in biological systems, coupled with detailed micro/ ultrastructural studies and theoretical calculations, creates the knowledge base for synthesizing optimum artificial structures.

E. Arzt, MSEC, 2006

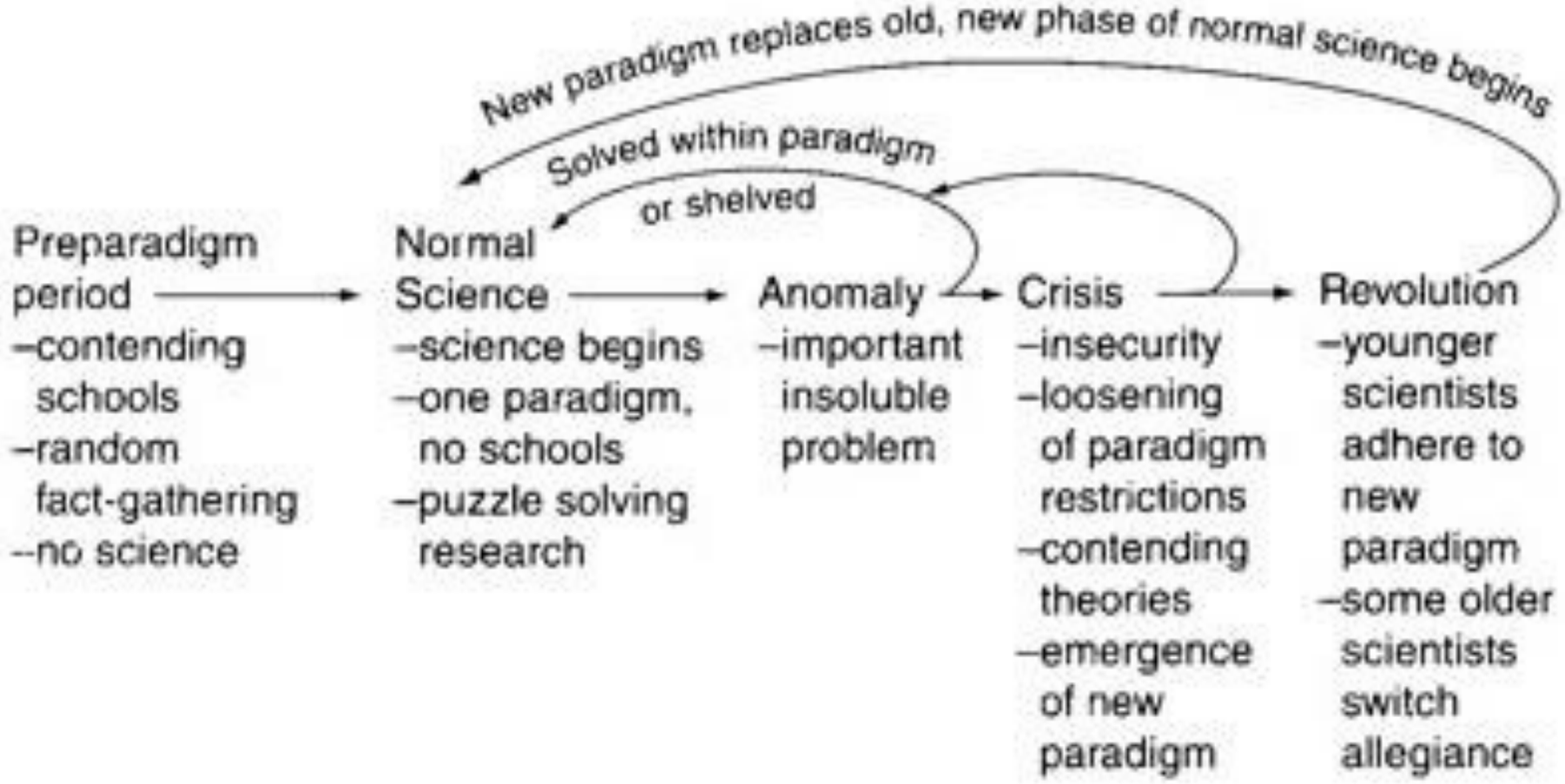
The Merged Paradigm

Modified Materials Engineering Paradigm (with Parallels to Biology)



Paradigm Shifts

FIGURE 1-1 The revolutionary character of paradigm shifts and the cyclical nature of science (a schematization of Kuhn, 1970).



https://johnwhawthorne.files.wordpress.com/2014/01/kuhns-revolutions.jpg

Satisficing

Good enough is
better than perfect.

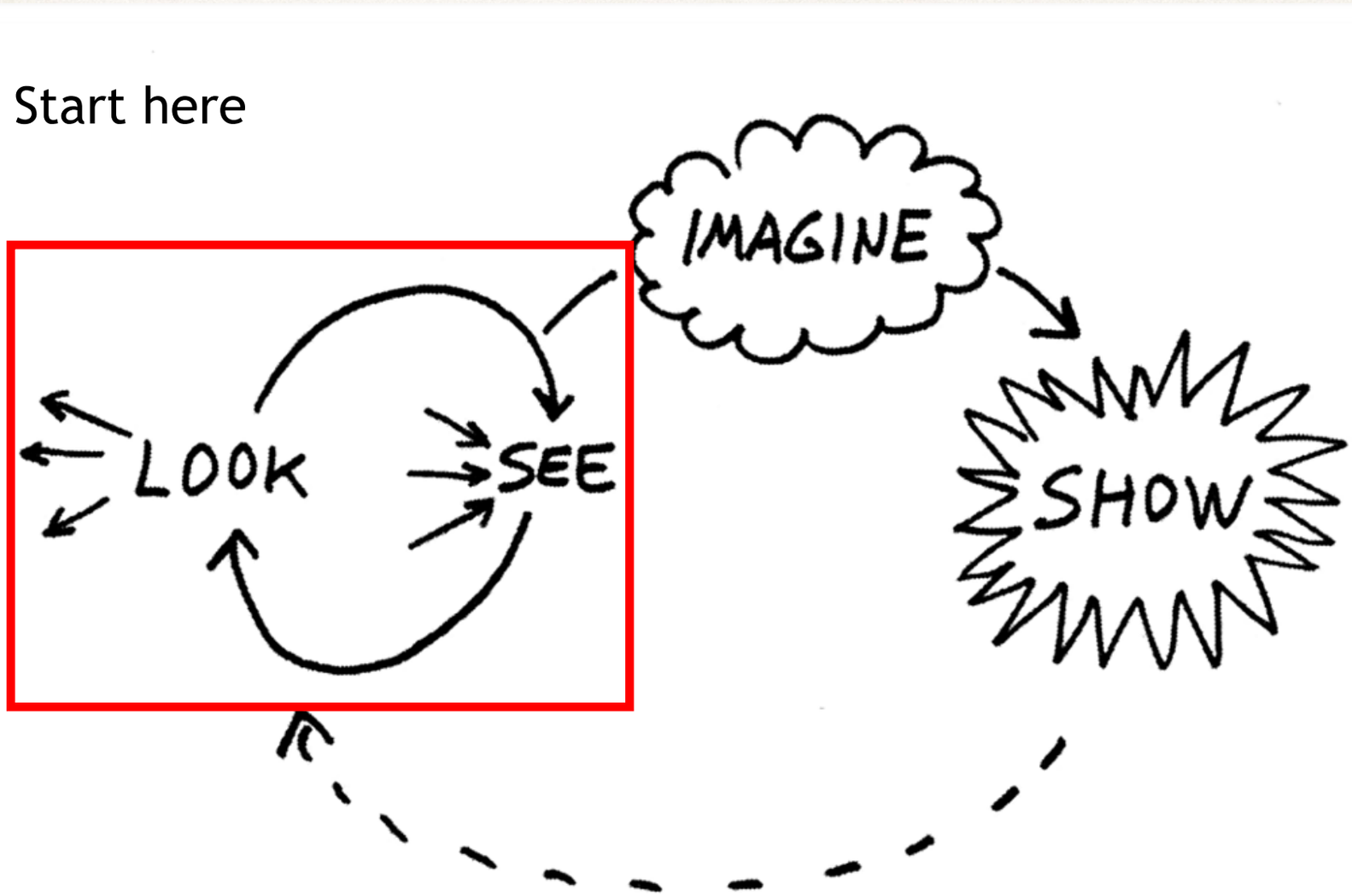
www.mashable.com

Life attempts to perpetually exist and it does so through countless iterations and errors.

We interpret life to place imaginary value.

Observation vs. Interpretation

The Visual Thinking Process

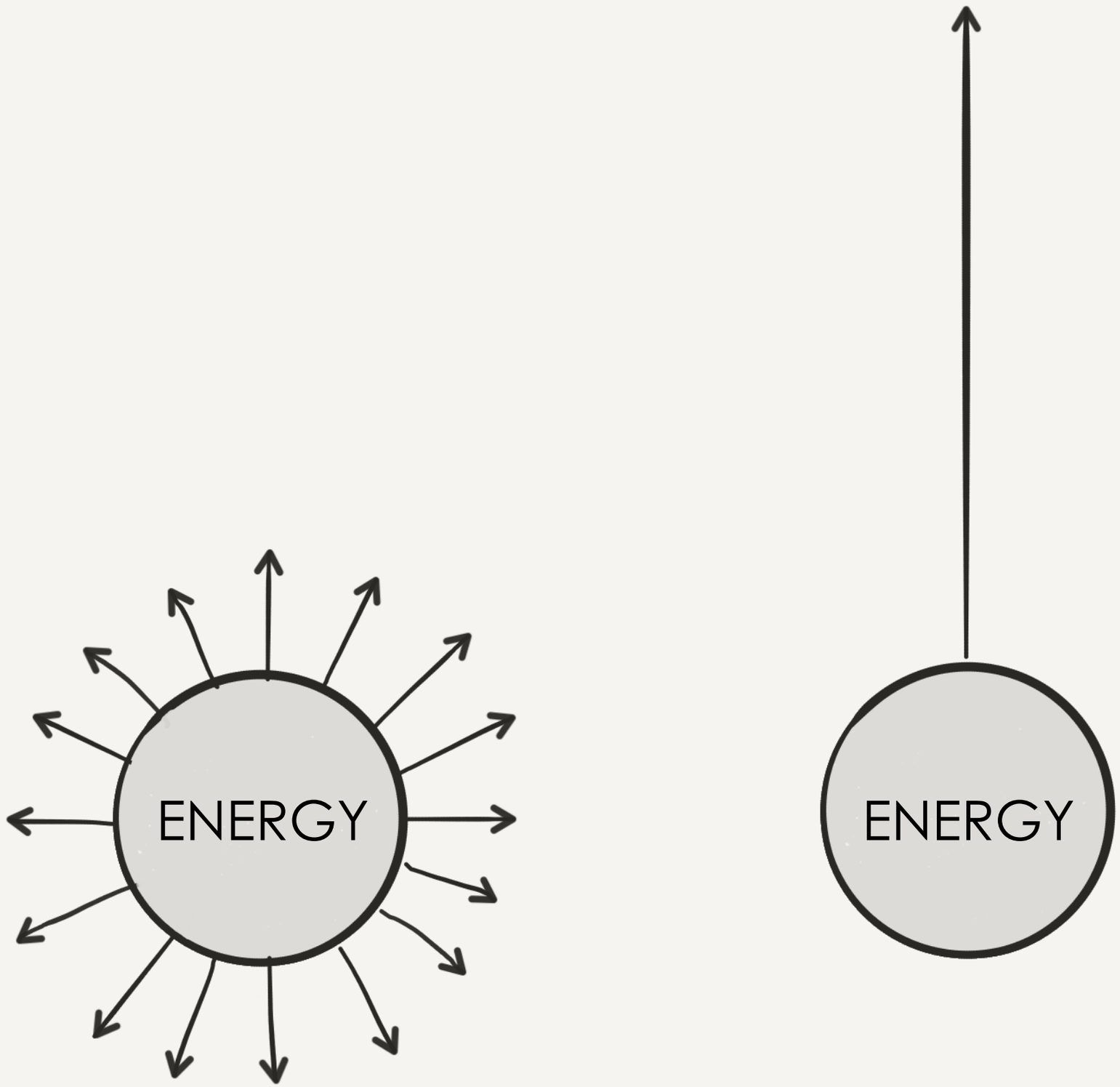


The visual thinking process, as it really happens.

D. Roam, “The Back of the Napkin: Solving Problems and Selling Ideas with Pictures,” Portfolio; Expanded Edition, New York, 2010.

Un Dimanche après-midi à l'lle de la Grande Jatte
By Georges Seurat, 1884
Photography (c) The Art Institute of Chicago

Nychka and Kruzic, 2013



After G. McKeown, *Essentialism*, 2014

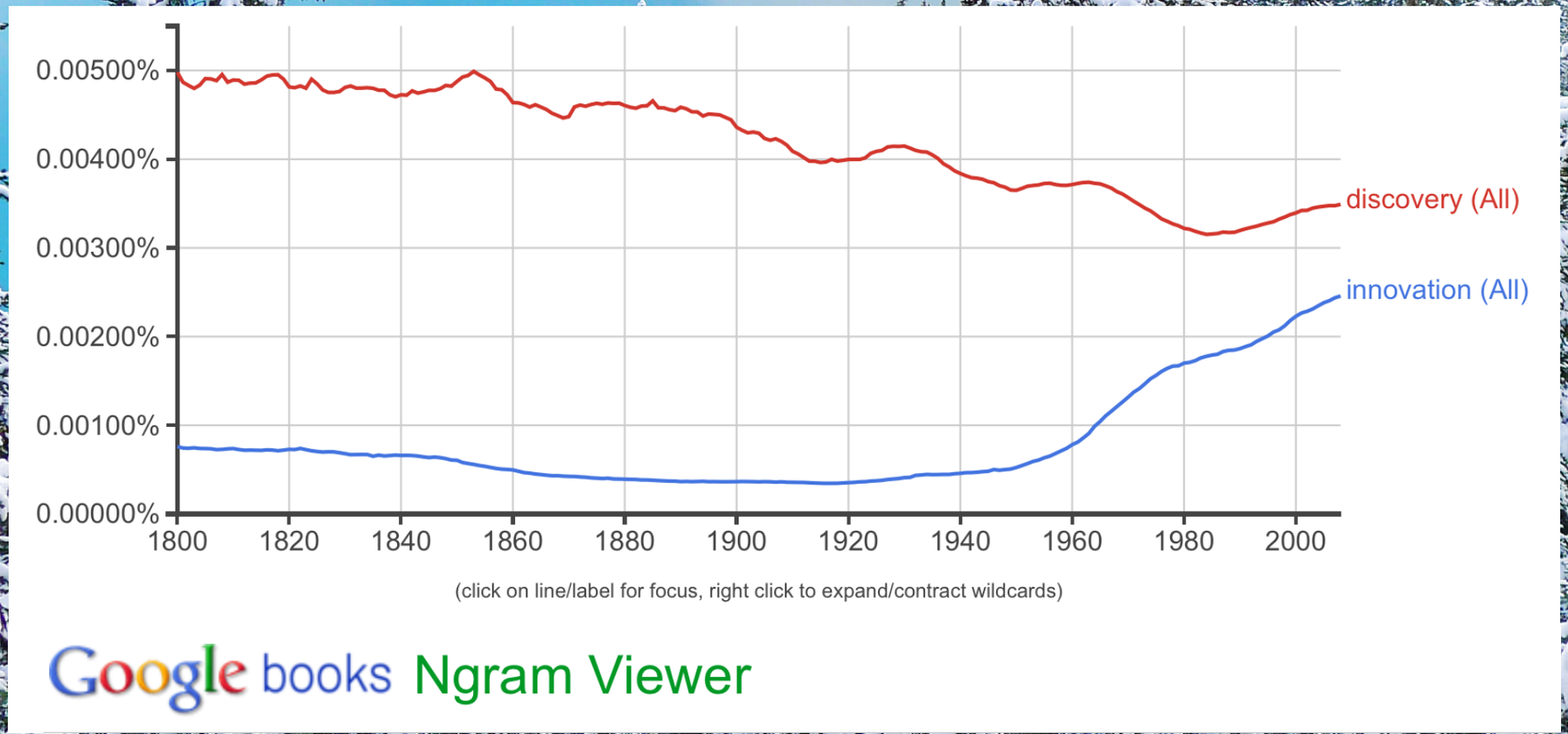
We need to pay attention to our biases and reasoning...

Causal Modeling

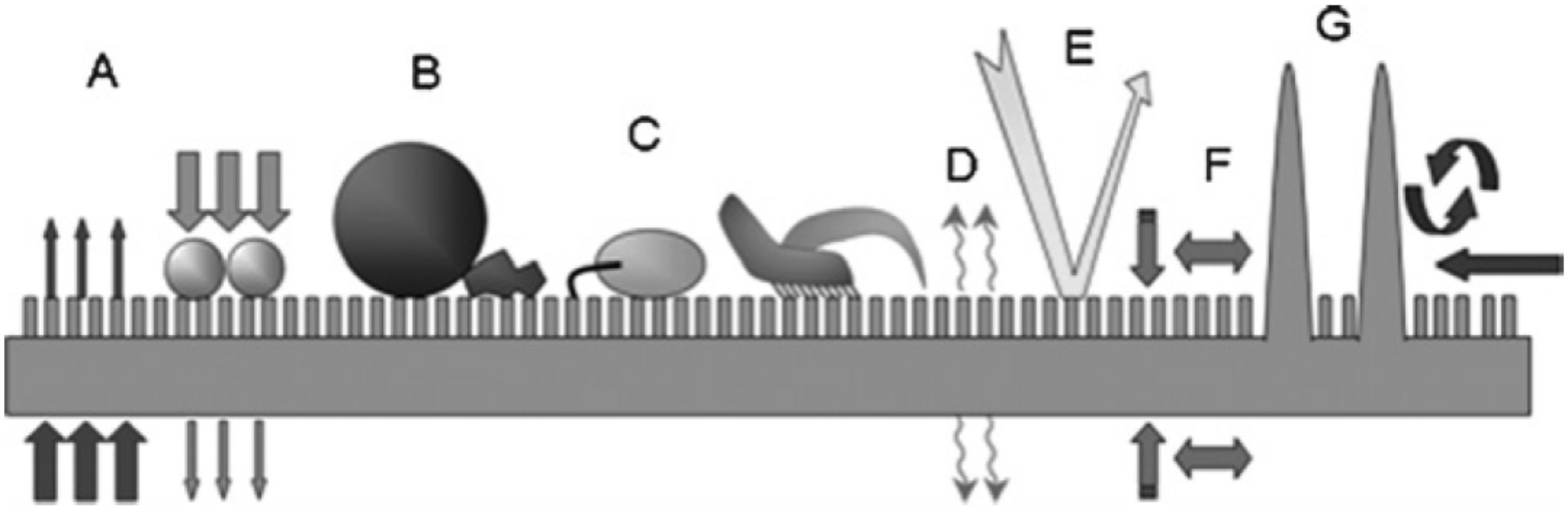
- **<u>Material Causation:</u>** under a certain set of conditions "x leads to y"

- **<u>Teleological Causation:</u>** what is the purpose of "y"? Why do we want "y" to happen?

Discovery vs. Innovation



Epicuticular wax functions



A: Transport barrier

B: Surface wettability

C: Anti-adhesive, self-cleaning properties

D: Signalling cues for pathogen detection and cell development

E: optical properties: protection from harmful radiation

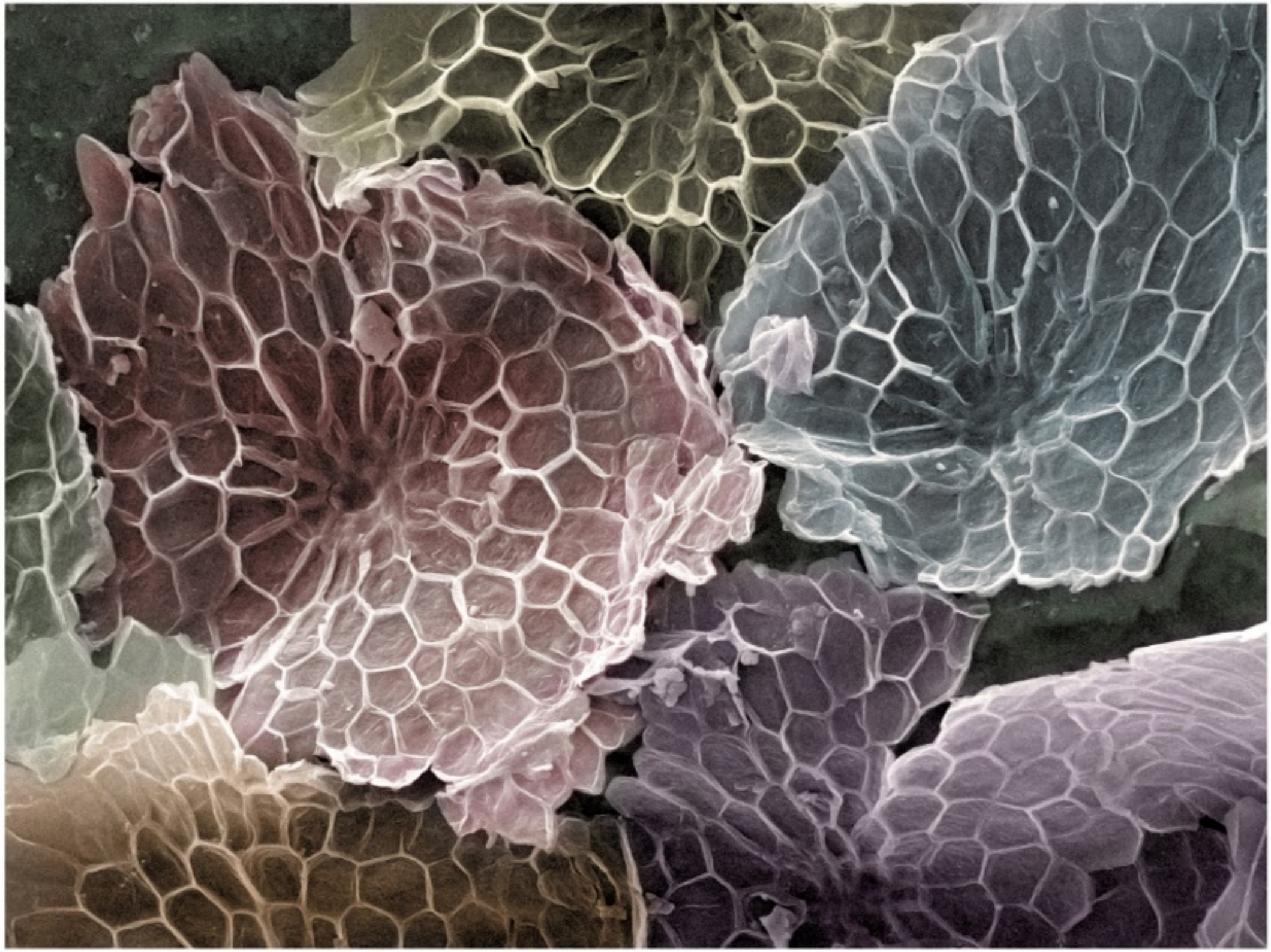
F: mechanical properties: physiologic integrity, resistance against mechanical stresses

G: Temperature control: reduction of surface temperature by increasing turbulent air flow

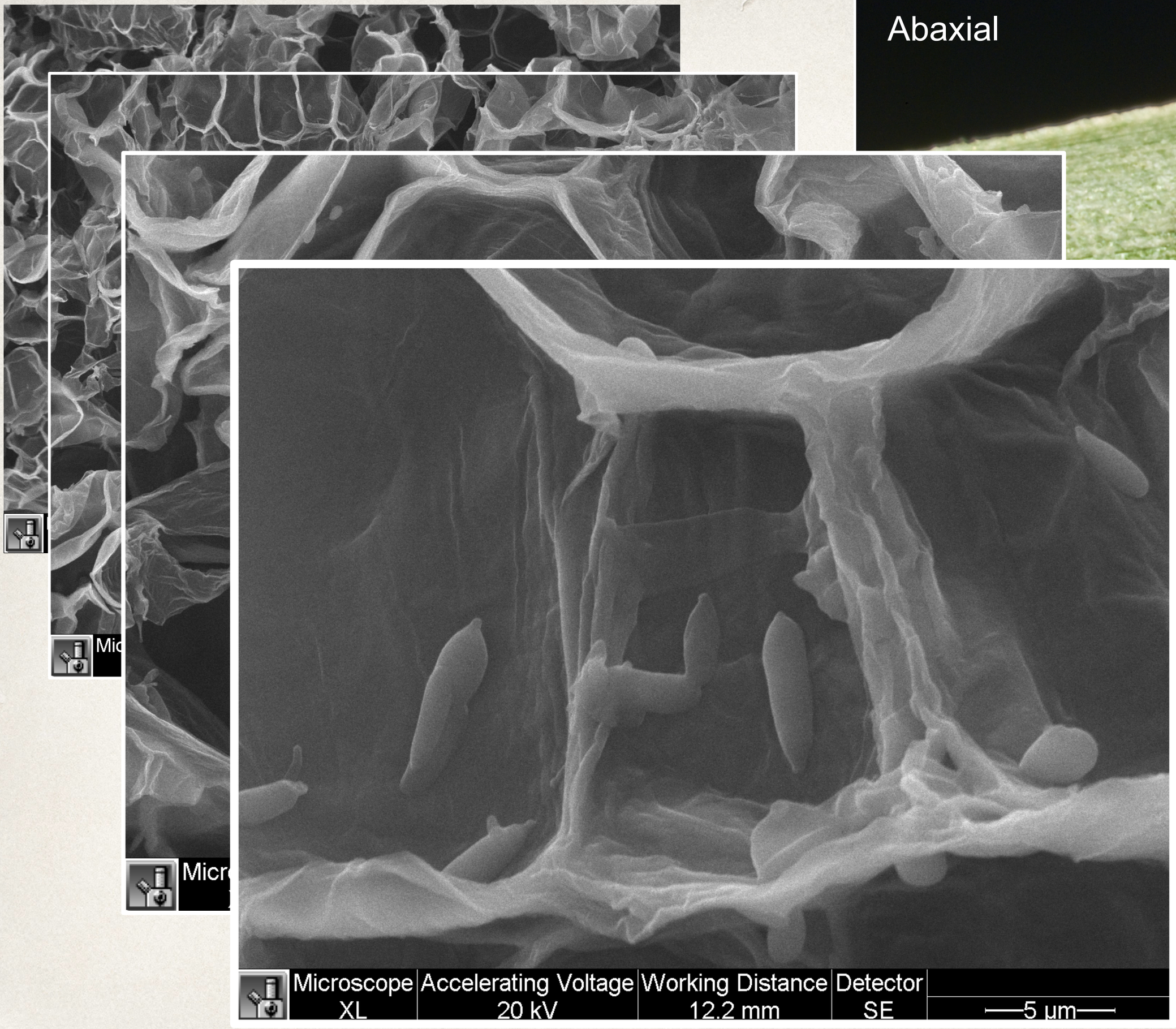
K. Koch *et al. Soft Matter* **4** (2008) 1943-1963

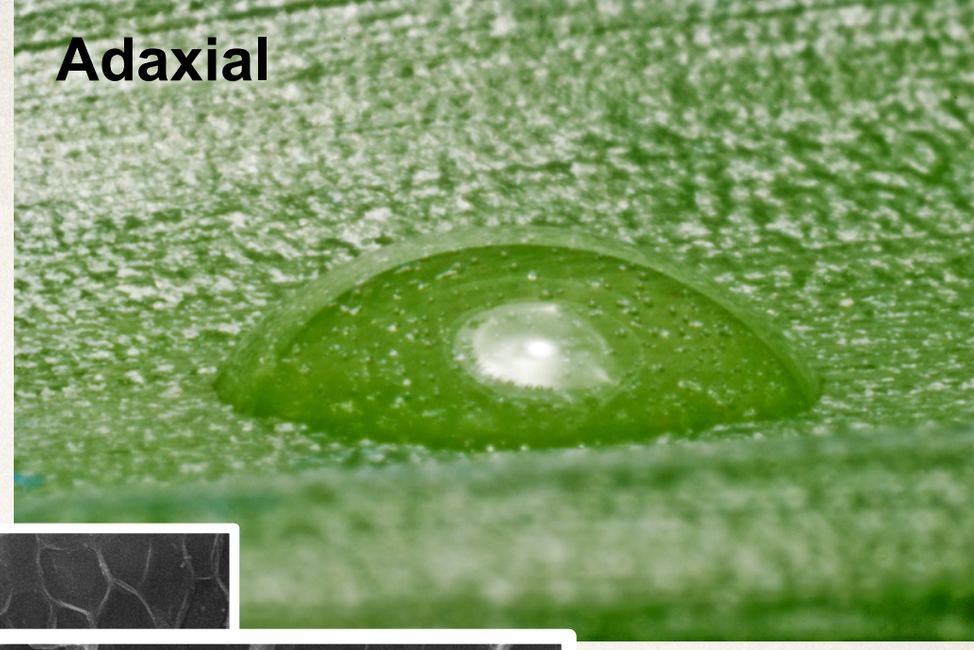
12

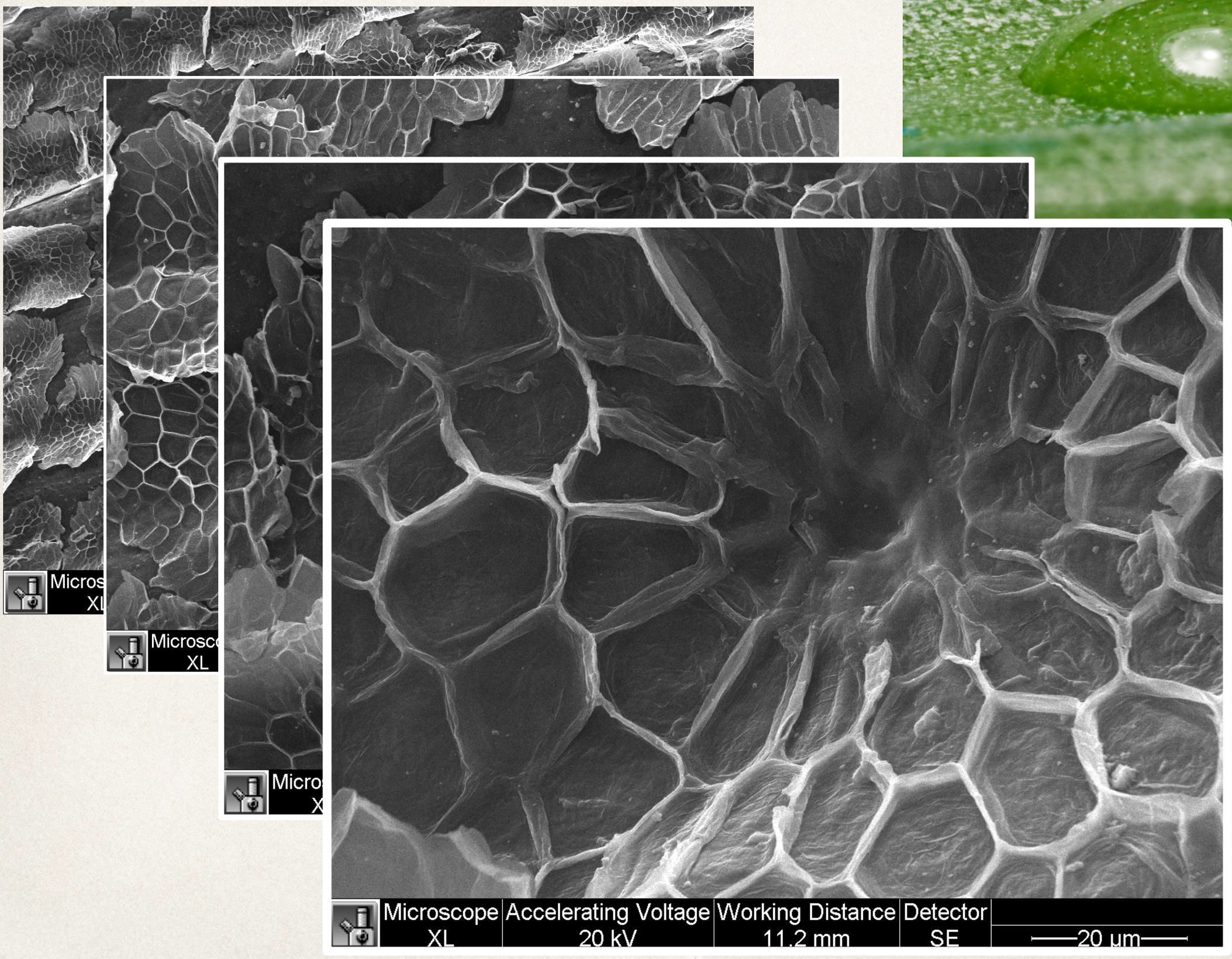
Example



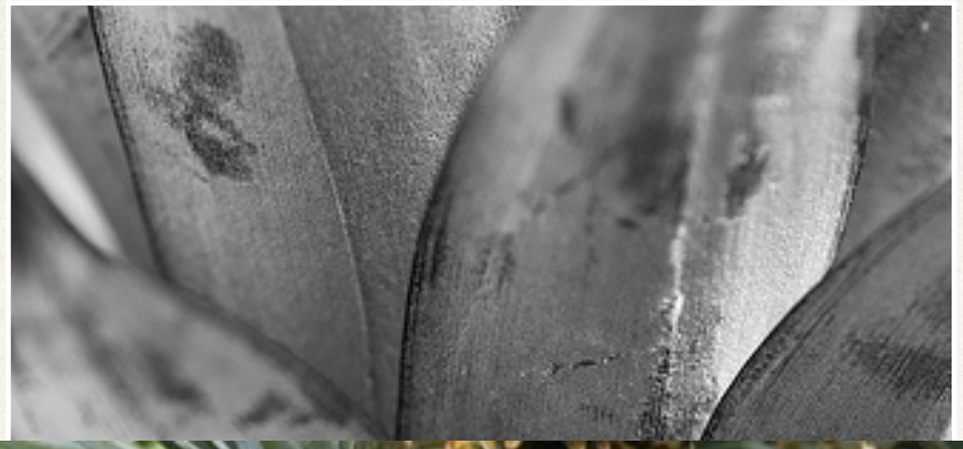
Abaxial


Microscope
XL
Accelerating Voltage
20 kV
Working Distance
12.2 mm
Detector
SE
5 µm

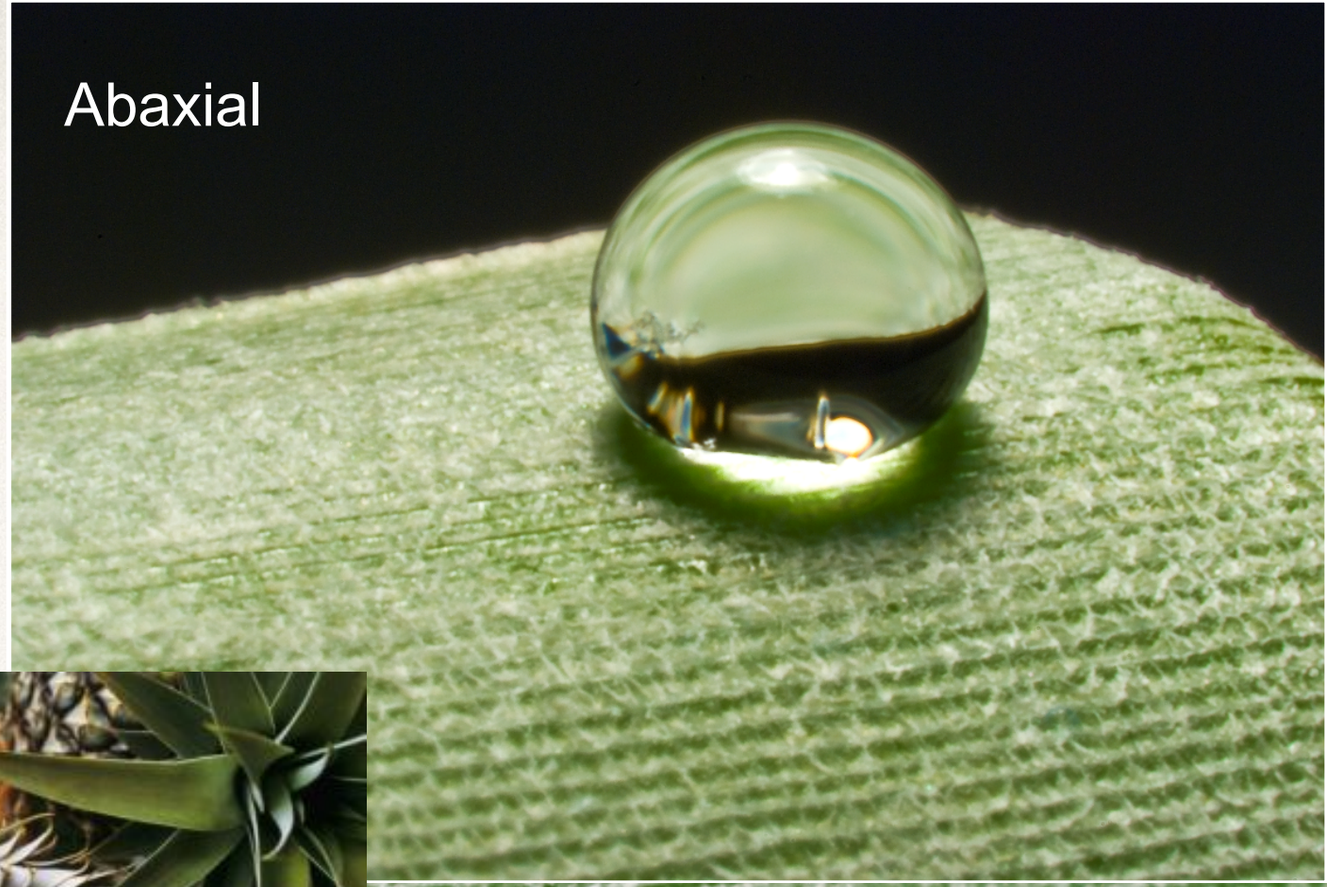

Adaxial

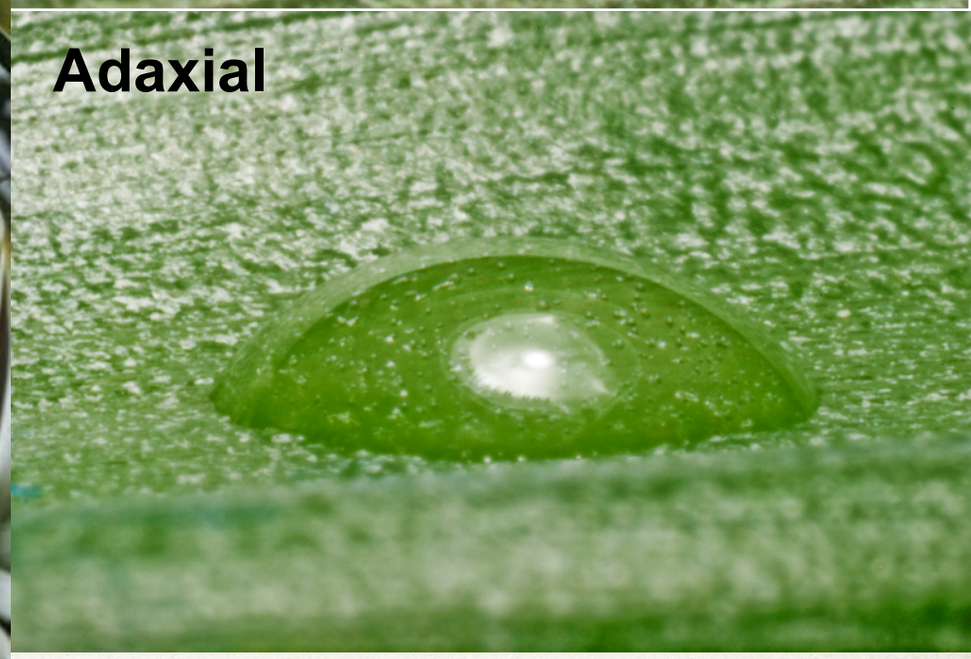

Micros
XL
Microsc
XL
Micro
X
Microscope
XL
Accelerating Voltage
20 kV
Working Distance
11.2 mm
Detector
SE
20 µm

Ananas comosus



WWW.FOTOBANK.RU FC02-8199 FoodCollection
Ripe and unripe pineapples (full-frame)

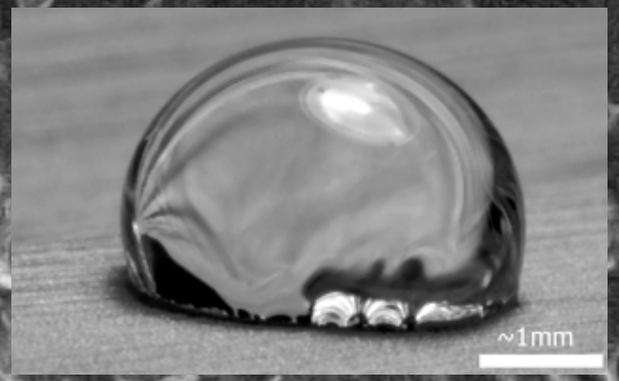




One of these images is of a sugar cane leaf.
The other is of an engineered ceramic coating.

Which is which?

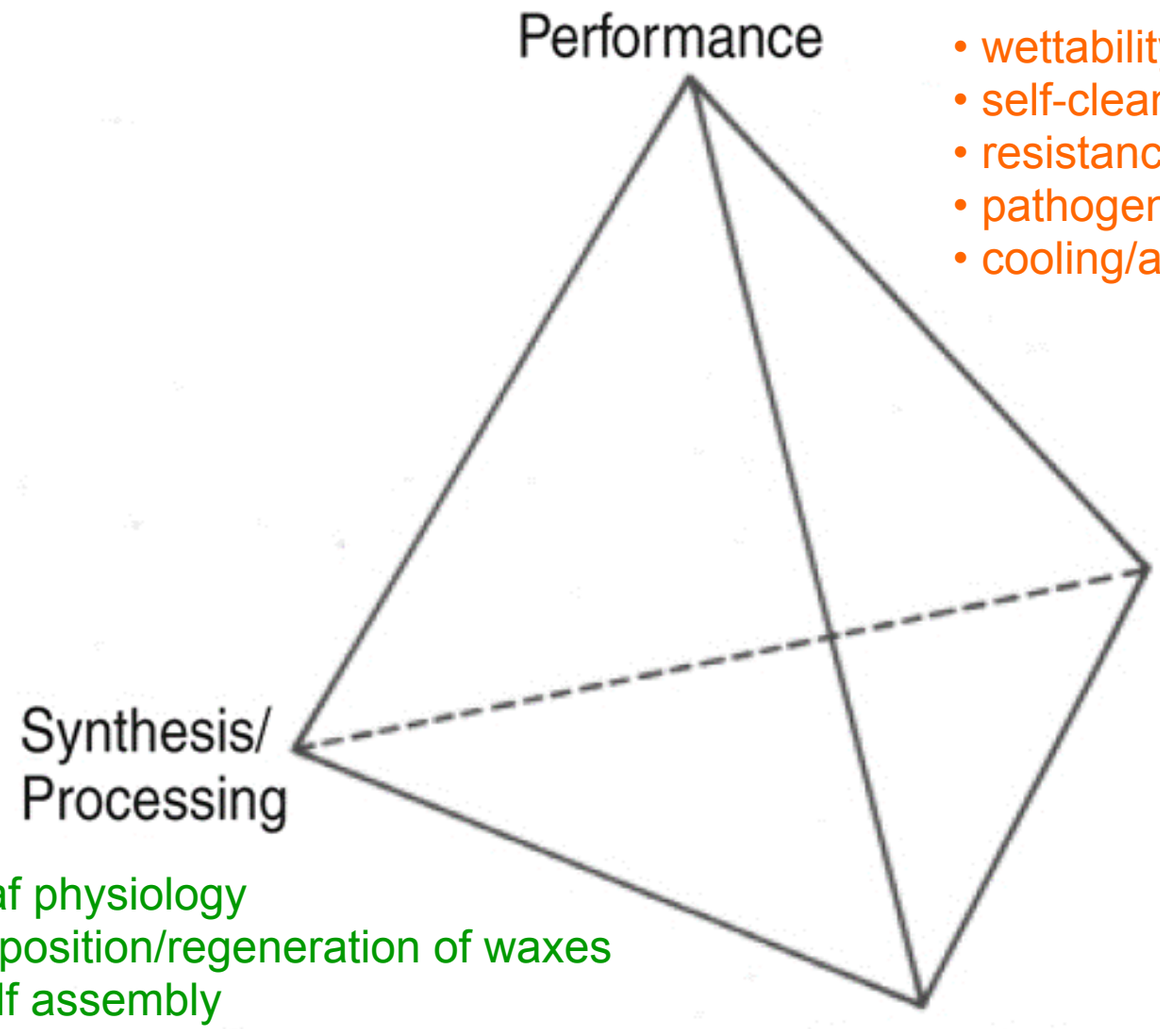
Alumina on stainless steel mesh



Sugar cane

5µm

This is all material causation… we also need to include critical teleological causation… i.e.,Why?



- wettability
- self-cleaning
- resistance to UV
- pathogen resistance
- cooling/air flow

- surface energy
- wear/abrasion resistance
- chemical resistance

- leaf physiology
- deposition/regeneration of waxes
- self assembly
- gene regulated
- room temperature
- atmospheric pressure
- handful of elements
- biomimetic materials

- leaf structure
- hierarchical structure of waxes molecular structure and chemistry of waxes
- types of micro and nanostructure of waxes

Tetrahedron: *Materials Science and Engineering for the 1990's: Maintaining Competitiveness in the Age of Materials* (Washington, D.C.: National Academy Press, 1989), http://www.nap.edu/catalog/758.html. Drafted by the Committee on MSE

Tips and myths...

- **Discovery**

- Nature contains all the answers just waiting to be found

- Discovery just happens

- Discovery involves exploration, research, investigation, and confirmation

- **Innovation**

- Innovation is about the newest thing

- Change is always good

- Innovation is a solo activity

- OLD + OLD = NEW

- Based on curiosity

"The art of discovery from the natural world lies in our ability to prevent blind assumption: we cannot assume we know all the design elements, constraints, or processes in place for a particular application in nature – we may not even know the original problem.

However, through careful study, discussion, and critical, analytical, and creative thinking we can use our discipline specific tools to synthesize our collected and nested knowledge to better our understanding and physical well being."

Nychka et al., MSEC 2011

Greed
Impatience
Arrogance
Selfishness
Demand


LIFE
is not a
STORY
about me

Attitudes for Progress

We know nothing.

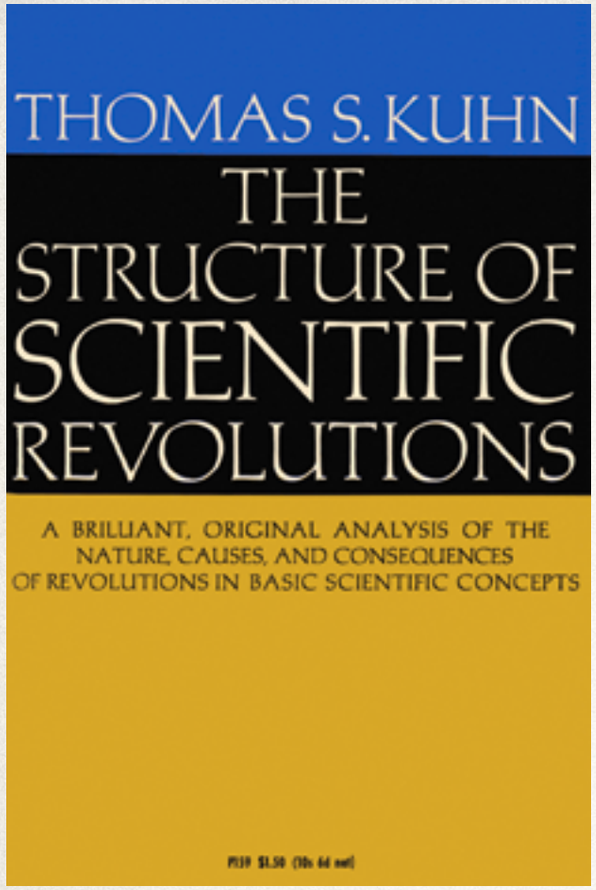
Nothing we try will work the first time. Iteration is required.

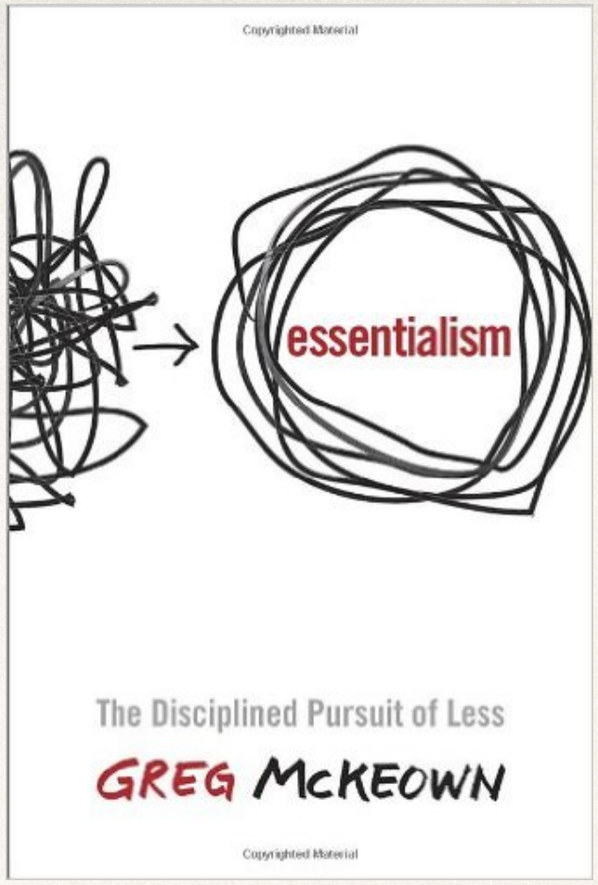
We will never completely know "why?", our biases limit us.

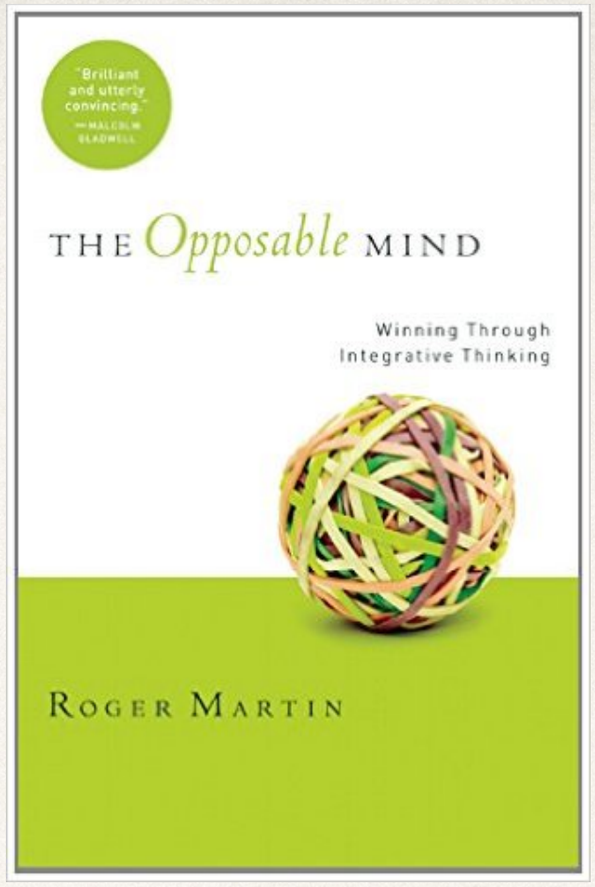
All models are imperfect... we need multiple models to help define the problem.

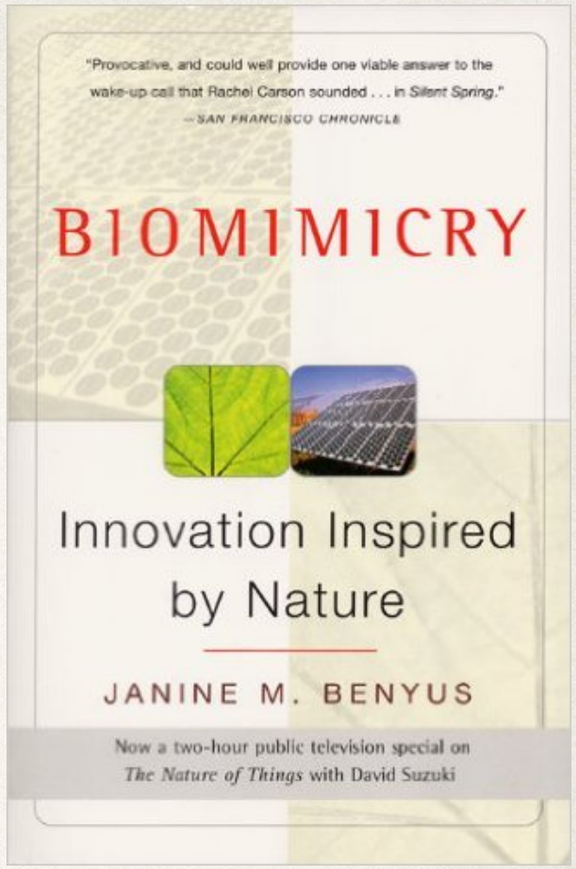
Paradigms are temporary.

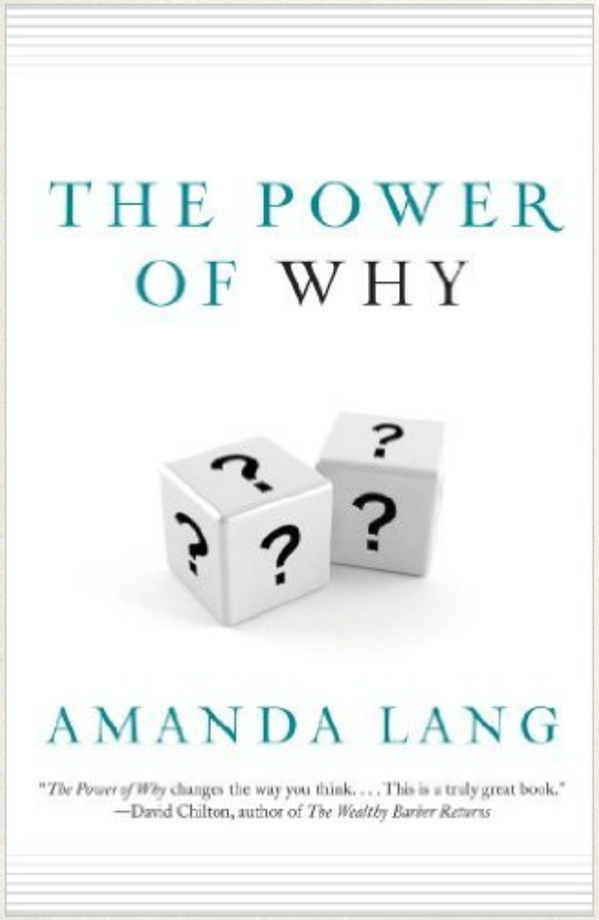
Opposing ideas contain insight - embrace them.

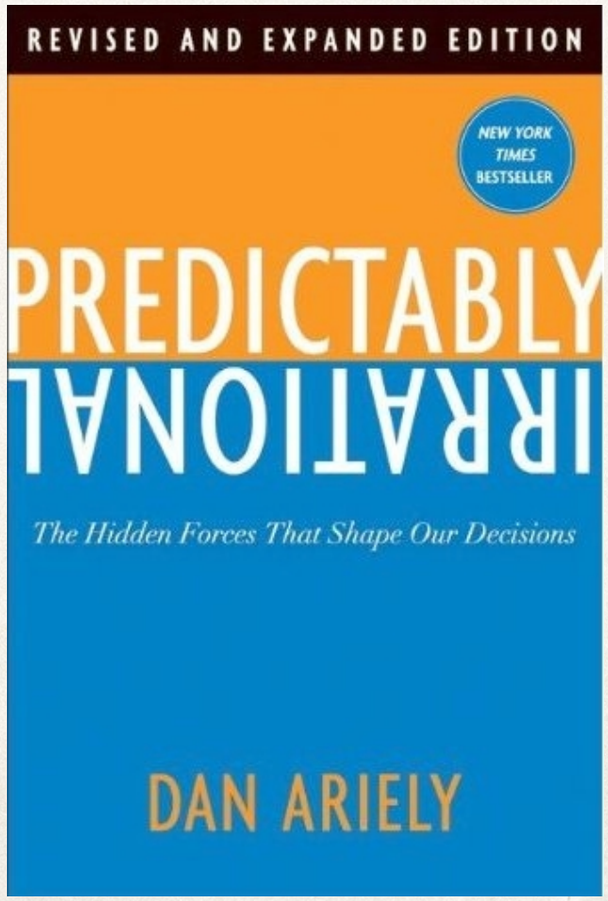












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